A Low Cost Open Source Hardware Tool for Integrated Learning Experience in Laboratories

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***Abstract*—As education and technology merge, the opportunities for teaching and learning increase even more. However, rapid rate of change in the fields of technology like in Electrical, Electronics and Computer poses special problems for the engineering disciplines and more so in the area of experimental work where major concerns arise. The challenge is to provide students with meaningful, up-to-date and relevant practical exposure within the limitations imposed by finite resources in laboratory infrastructure. Probably one of the viable solutions is to interface students and physical world using computer based techniques. This paper presents some thoughts and demonstrate some implementations on using a low cost open source hardware tool "expEYES" along with existing laboratory equipment in order to give a flexible, easy to evaluate new ideas, attractive and stimulating natural curiosity in students for gaining integrating learning experiences in the laboratories.**

I. Introduction

Emerging issues in an engineering institution are how to educate students effectively, how to facilitate experiential learning within a limited number of contact hours, how to integrate concepts learnt in different courses and how to make students industry ready [1].

In addition to these, specifically in laboratory practices, rapid changes in technology fields like in Electrical, Electronics and Computer impose special problems for the institutions. There is of course a greater demand on faculty for continual update and augment the content of the lecture courses to keep pace with this change, but it is in the area of experimental work where major concerns arise. The challenge is to provide students with meaningful, up-to-date and relevant practical exposure within the limitations imposed by finite resources in laboratory hardware and infrastructure. Probably one of the viable solutions is to interface students and physical world using computer based techniques [2].

Nowadays, many academic courses that teach engineering subjects have already begun incorporating computer-based educational tools for student use, either in the lectures or in the laboratory practices or both [3].

Further, as we know, engineering subjects are bit involved, it is beneficial for students if laboratory experiments demonstrate functional interaction between other topics learnt. It is especially true with Electrical Engineering unless problem solving is supported by the relevant laboratory practice. The laboratory environment must provide common practical experience to cater for students who are from diverse backgrounds. Their learning will be more effective if appropriate context is set [4].

In the laboratory applications, from the technical point of view, all the engineering problems deal with some physical quantities such as current, voltage, pressure, force, torque, temperature, speed, position etc. A computer equipped with the suitable interface circuits, data acquisition systems and software, can give graphical visualization of these quantities, and can process the acquired data [5].

Although a number of computer-based customized test systems have been developed within the past ten years to replace the conventional engineering experiments, commercially available computer-controlled systems suitable for educational institutions have many limitations [6]. They are:

- Inflexible and unfamiliar programming structure
- Not compatible with existing experimental setup
- Expensive to buy/convert
- Normally designed in a modular structure, wherein all available options may not be required
- Neither students nor community can contribute to its growth

An advanced teaching/learning laboratory can be developed by purchasing completely new equipment. However, this approach is an expensive solution for academic institutions. An alternate cost-effective solution is to take the old laboratory, proven systems, and retrofit them with the computer data acquisition systems and develop custom-written software to suit the existing experimental modules [7].

This paper presents some thoughts and demonstrate some implementations on introducing a low cost open source hardware tool "expEYES" along with existing laboratory equipment in order to give a flexible, easy to evaluate new ideas, attractive and stimulating natural curiosity in students for gaining integrating learning experiences in the laboratories. The paper is organized as follows: Section II of this paper will introduce an open source hardware tool "expEYES" designed for conducting hardware and/or software experiments. A case study on 'Closed Loop Speed Control of a PMDC motor' using aforementioned tool is presented in Section III. Reflections of a group of four students who used this hardware tool for experimentation is shared in Section IV. Finally, conclusions are drawn in Section V.

Fig. 1. expEYES Junior top panel

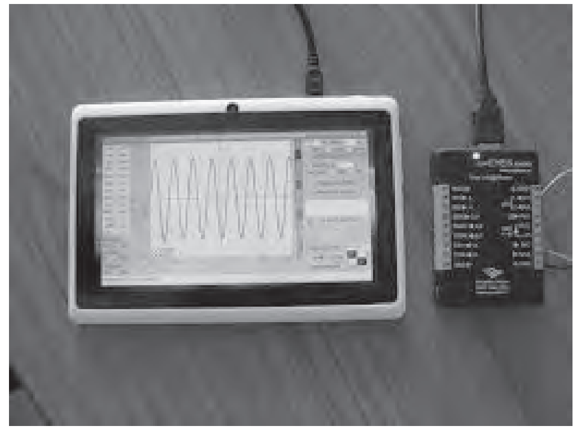

Fig. 2. expEYES Junior on Android Tablet

II. ExpEYES Junior

ExpEYES Junior (http://expeyes.in) is developed by Inter-University Accelerator Centre (IUAC, Web : www.iuac.res.in), New Delhi, India, under Physics with Home-made Equipment & Innovative Experiments (PHOENIX) project started in 2004 with the objective of improving the science education at Indian Universities. In addition to this, other major objectives include development of low cost laboratory equipment and training teachers under this project.

It is meant to be a tool for learning by exploration, suitable for young engineers and scientists. The design is optimized to be simple, flexible, rugged and low cost. Because of low cost, it enables students to perform experiments both in laboratories and beyond. Hardware design is open source and royalty-free. The software is released under GNU General Public License. The project has progressed due to the active participation and contributions from the user community and many other persons outside IUAC. The following are the salient features of expEYES Junior [8]:

- Built-in Signal Generator and CRO
- USB Powered
- 12 bit Analog to Digital Converter
- Open Source Hardware and Free Software
- Uses Python programming language
- Compact, 8.6 x 5.8 x 1.6 cm, 60 gm
- Low Cost about $ 33.0

Nowadays, it runs also on Android Tablets encouraging students to carry out experiments as well as explore them, not just within the college campus, even beyond. Android version of expEYES software can be installed from Google Play store. Currently it works only on Android versions 4.0.0 and above. Requires USB OTG support in hardware and the USB API software in the OS. Drawbacks of Android version is that one cannot write simple Python scripts to perform experiments, the way it is possible on the GNU/Linux version. A screen shot of an Android Tablet running expEYES application is as shown in Fig. 2.

Rasberry Pi is UK's low cost ($35.0), credit card sized computer board that runs GNU/Linux. This is the result of initiatives taken by a group of people who are concerned about the decline of computer skill levels among their students, and their solution has become a huge success. Recently, expEYES is being used with Rasberry Pi to conduct many more experiments. Since, both projects follow the open source philosophy and combining the cost advantages, result in a science laboratory that can grow with the requirements of the user. The following are the additional features available for the user after combining these hardware together:

- Measure/control voltages with 12 bit resolution
- Generate/Capture waveforms and analyse them mathematically
- Everything controlled from simple Python programs

A. Features

ExpEYES Junior is interfaced and powered by the USB port of the computer. For connecting external signals, it has several Input/Output terminals, arranged on both sides, as shown in Fig. 1. It can monitor and control the voltages at these terminals. In order to measure other parameters (like temperature, pressure etc.), it is necessary to convert them in to electrical signals by using appropriate sensor elements. This tool can be used to develop new experiments other than illustrated ones from developer by writing few lines of code in Python language. All the communication to expEYES is carried out using Python library called *eyesj.py* [9]. Data analysis and graphical display is carried out also in Python. If you are interested in developing new experiments based on expEYES, it would be a good idea to learn Python programming language. Various external connections available on the tool are given below:

1) Programmable Voltage Source (PVS): This pin output can be set, from software, to any value in the 0 to +5V range. The resolution is 12 bits.

2) $\pm$ 5V Analog Inputs (A1 & A2): These two input pins can measure voltage within the $\pm$5 volts range. The resolution of ADC is 12 bits. Voltage at these terminals can be displayed as a function of time, giving the functionality of a low frequency oscilloscope. The maximum sampling rate is 250,000 per second. Both have an input impedance of 10 M Ω.

3) 0–5V Analog Inputs (IN1 & IN2): These terminals can measure voltages in the 0 to 5V range.

4) Resistive Sensor Input (SEN): This is mainly meant for sensors like light dependent resistor, thermistor, Photo-transistor etc. SEN is connected to 5 volts through a 5.1 kΩ resistor. It also has a built-in analog comparator.

5) Digital Inputs (IN1 & IN2): Inputs IN1, IN2 can act as both analog and digital inputs.

6) Digital Output (OD1): The voltage at OD1 can be set to 0 or 5 volts, using software.

7) Square Waves SQR1 & SQR2: Output swings from 0 to 5 volts and frequency can be varied 0.7 Hz to 100 kHz. SQR1 and SQR2 can be set to different frequencies. It is also possible to set them to same frequency, with a specific phase shift between the two. These outputs also can be programmed to generate Pulse Width Modulated waveforms.

8) Infrared Transmission: An Infrared Diode connected to SQR1 can transmit data using IR transmission protocol. The 4 byte transmission can be used for emulating common TV remotes.

9) SINE wave: Fixed frequency sine wave generator, of frequency around 150 Hz. Bipolar signal output with an amplitude of around 4 volts.

10) Constant Current Source (CCS): The constant current source can be switched ON and OFF under software control. The nominal value is 1 mA but may vary from unit to unit.

11) Microphone (MIC): There is a built-in condenser microphone (on the side, near CCS). Its output, amplified 51 times, is available on MIC output.

12) Inverting Amplifier (IN $\rightarrow$ OUT): The inverting amplifier is implemented using TL084 op-amp, giving a maximum gain of 51.

13) Ground: The four terminals marked as GND are the reference ground. All the generated/measured voltages are with respect to these terminals.

Various details of hardware design which includes block diagram, circuit schematics, PCB Gerber files and parts list can be downloaded from http://www.expeyes.in/design-of-expeyes.

B. Software Installation

ExpEYES can run on any computer having a Python Interpreter and a Python module to access the Serial port. The USB interface is handled by the device driver program that presents the USB port as an RS232 port to the application programs. ExpEYES software is available in the form of live CD or can be downloaded from http://expeyes.in/software-installation both for MS Windows and Linux platforms.

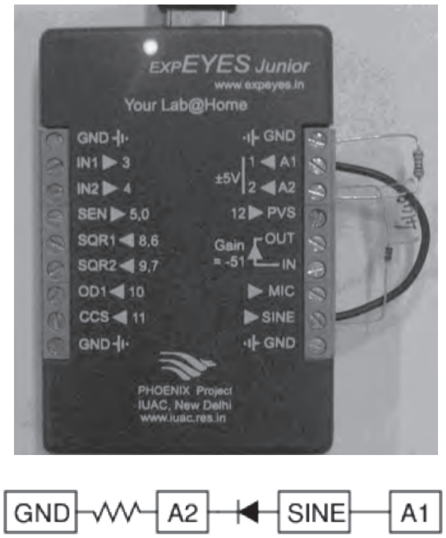

Fig. 3. Circuit connection for half wave rectifier

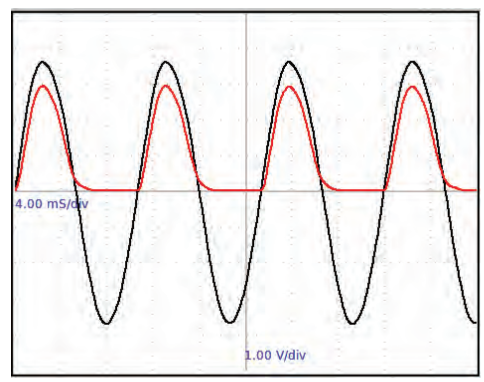

Fig. 4. Input and output waveforms for half wave rectifier

C. A Quick Demonstration of using expEYES in Laboratory

Let us assume that we would like to conduct an experiment to understand the working principle of a half wave rectifier with and without capacitance filter circuit, say for freshmen under-graduates. This subsection shows how to use expEYES for doing aforementioned experiment.

Fig. 3 shows how different circuit components can be connected to various input/output terminals of expEYES. It can be seen that making circuit connections is very simple and easy. Fig. 4 shows input and output waveforms of a half wave rectifier. Looking at this figure, it is very easy to understand the effect of diode resistance during its conduction or how does it influences output voltage value. Now if a filter capacitor (C) is connected across the load resistor, it is easy to see the effect of this on output voltage as shown in Fig. 5. This kind of setup encourages students to explore and learn from each

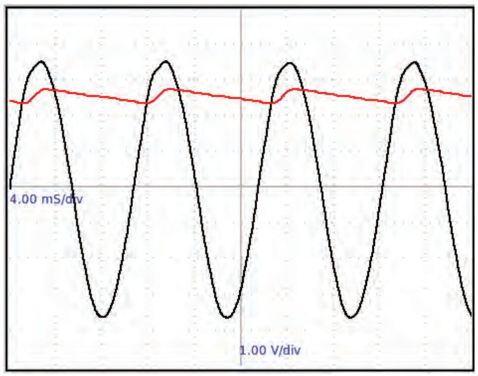

Fig. 5. Input and output waveforms for half wave rectifier with C filter

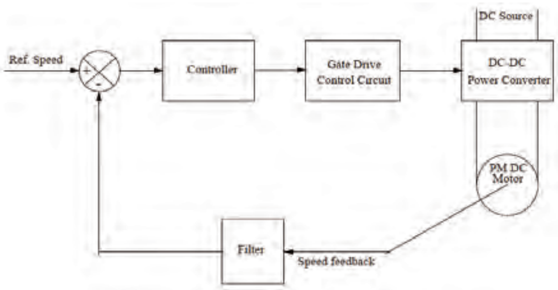

Fig. 6. Closed loop speed control of PMDC motor

experiment within the college campus and beyond. It should be noted that Figs. 4 and 5 have been captured from CRO plus feature of expEYES.

III. A Case Study on Integrating Learning Experience Using expEYES

In an integrated laboratory learning environment, a well designed experiment is expected to weave the learning experiences in different courses together. By doing this experiment in the laboratory, the inter-relationships and inter-dependencies of the various courses are clearly illustrated. This experiment represents what the student has learned, how it is applied, and how it relates to other subjects he or she has learned in other classes.

The hardware tool used during experimentation must be flexible so that students may easily experiment and evaluate new ideas. A flexible platform encourages exploration by making new creations easier to make. The flexibility of the platform should make experimentation easy and attractive. If possible, the natural curiosity in students should be stimulated. This stimulation leads to learning through discovery. The discovery learning process is most satisfying one that helps generate the desire for life-long learning.

We are planning to introduce an experiment in Control System Laboratory at 5th semester on “Closed Loop Speed Control of a Permanent Magnet DC (PMDC) Motor” in structured inquiry experiments category.

The schematic block diagram of this experiment is as shown in Fig. 6. The aim of this experiment is to keep rotational speed

Fig. 7. Integration of concepts of various courses

of the dc motor at a constant value as defined by the user (also known as reference speed), even when there are variations in load torque and supply voltage. Actual speed of the motor is sensed through an optical sensor which is mounted on the motor platform. Actual speed signal is processed through a low-pass filter so as to filter out unwanted high frequency components. The difference between reference and actual speeds is calculated using a summer to obtain speed error. A controller will process this error, so as to minimize the difference between reference and actual speeds. Controller output will set the gain of the dc-dc converter, which in turn alters input voltage to dc motor according to the gain set by the controller.

As an example, let us say that the reference speed is more than the actual speed. Then the speed error is positive and controller will increase the gain of the dc-dc converter. Since gain of the converter has increased, applied voltage to the motor is increased which will increase actual speed of the motor, thus minimizing the error. The controller will behave exactly opposite to what has been explained above, if the speed error is negative.

Fig. 7 illustrates the use of concepts from various courses studied during previous semesters in conducting this experiment. The following Table I lists concepts learnt from various courses used during the experimental realization of different blocks/activities as shown in Fig. 6. It can be seen from Fig. 7 and Table I that, this experiment provides an opportunity for weaving learnt concepts from different courses together and also imparts experiential learning for students.

ExpEYES has been used to implement the following blocks / activity:

- Definition of reference speed
- Summer implementation
- Controller and
- Conversion of analog speed feedback signal into digital

TABLE I
INTEGRATION OF CONCEPTS LEARNT IN VARIOUS COURSES

Course name	Components of block diagram/activity
Circuit Analysis	Speed feedback Filter Gate drive and control circuit DC-DC power converter PMDC motor
Analog Electronics	Speed feedback Filter Gate drive and control circuit DC-DC power converter
Electrical Machines	PMDC motor and its speed control
Digital Electronics	Speed feedback Controller Gate drive and control circuit
Micro-controller(μC)	Programming expEYES Interfacing expEYES with other components
Power Electronics	Gate drive and control circuit DC-DC power converter
Engineering Design	Finding alternate solutions for blocks circuit realization and implementation of entire system
Embedded Systems	Integration and co-ordination of of various blocks and programme scheduling of expEYES

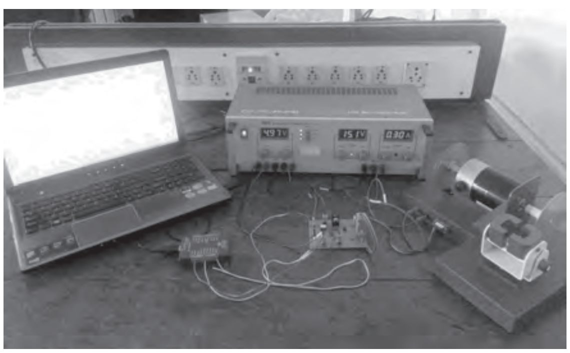

Fig. 8. Experimental setup

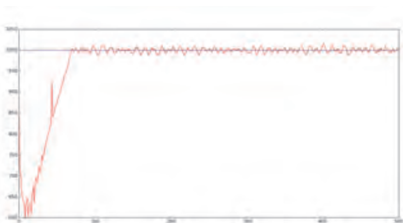

Fig. 9. Motor speed response with constant load torque

A. Experimental Results

Fig. 8 shows the experimental setup in the laboratory. All the components of schematic block diagram can be seen in this figure. As an example, the reference speed of the motor is set at 1000 rpm and the motor actual speed response is shown in Fig. 9. It can be seen from this figure that the speed of the motor increases initially towards the reference speed and then it becomes equal. Generally, speed of the motor decreases as the applied load torque is increased. But with the closed loop feedback control, it is expected to keep the speed constant in

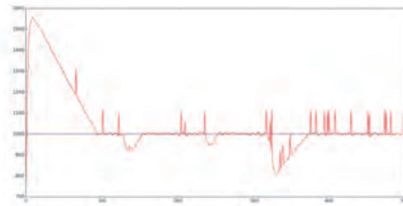

Fig. 10. Motor speed response for an increase in load torque

Fig. 11. Duty cycle variation when reference speed is increased

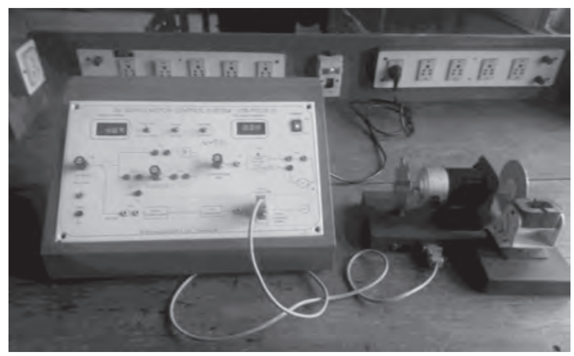

Fig. 12. Existing experimental setup

Fig. 13. Identical experiment setup using NI's resources

spite of the increase in load torque. Fig. 10 shows the effect of change in load torque on the speed of the motor. Speed of the motor drops momentarily when there is an increase in load torque, but later on, the motor speed will be at its reference/set speed as can be verified from this figure. Fig. 11 shows an increase in duty cycle of gate drive pulses when the reference speed of the motor is increased. Increase in duty cycle of gate drive pulses will in turn increase the average output voltage of the power converter which will cause an increase in speed.

Fig. 12 shows existing experimental setup for doing aforementioned experiment. Comparing this figure with Fig. 8, it can be seen that former experimental setup is not flexible and easy to evaluate new ideas and cannot provide stimulating experience. An identical experimental setup using National Instrument's hardware and software (Labview) is depicted in Fig. 13. Conducting experiment on this setup is easy and convenient except for the prohibitive cost of hardware and software.

While expEYES has been successfully used for this experiment, the following are the limitations of the tool experienced when using it for motion control applications:

- Available ADC channels are limited
- Not possible to program timers according to application requirements
- When expEYES input and output ports are being accessed through programming, CRO plus feature is not available
- Cannot generate multiple ($\geq$ 3) PWM waveforms
- Uses Python interpreting language, hence cannot be used for real-time/time-critical applications

IV. Students Reflections

The initial experience using the board was decent. They faced problems on Microsoft Windows platform, and thus decided to evaluate the board on Linux platform. The experience on Linux platform was much better. Once all the necessary packages were installed it was easy to dump the code onto the expEYES board and perform the experiments. The CRO plus feature was also working without any problems. The only glitch was that, at times they needed to repeatedly unplug the device and then plug it back, as an error regarding the connection of the device was being shown.

Given that it was primarily developed for inculcating the concepts of basic sciences for young engineers and scientists, expEYES is quite capable, as they have discovered, for use in other applications as well. It can be used as a powerful tool to emulate laboratory environment with nothing more than a laptop and the expEYES board itself. As the programming for the board is done through Python, it becomes even easier to run any program/algorithms, since Python is quite an easy language to learn. The absence of an additional programmer/debugger is a big plus, as it reduces the muddle of interfacing it to our PC. Thus making it a great platform for beginners to explore the embedded domain. Also, those from non-electrical/electronics background with no base in the embedded field will find this platform very easy to use in multi-disciplinary projects, if they have a basic understanding of using Python.

V. Conclusion

This paper presented some thoughts and also demonstrated some implementation of using a low cost open source hardware tool "expEYES" in order to give a flexible, easy to evaluate new ideas, attractive and stimulating natural curiosity in students for gaining integrating experience in the laboratories. Although this hardware tool has some limitations as pointed out in Subection III-A, it has the following advantages:

- It supports open source hardware concept
- It uses open source and free software "Python"
- The cost will be less than $33.0 when mass produced
- Each student can own this tool and use for other laboratories also
- Flexible enough to evaluate new ideas, to understand by the students and will be easy to form into something new
- It can match the needs of the students capability and be able to grow with them as they progress through the learning process both in hardware and software components
- Encourages community participation hence tools' feature enhancement will be faster and available free of cost for students

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