Physics with Home-made Equipment and Innovative Experiments

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1 Introduction

Progress in science is achieved through advances in both theory and experiments. Theoretical predictions must be verified by experiments and new experimental results leads to fresh theoretical developments. The role of experiment has become more significant due to the dominance of technology in our lives. Nowadays the ability to convert progress in science to technological products decide the future of any nation. This capability can only be achieved by making science education strong in both theory and experiment, which demands good laboratory facilities. Over the past several years, the laboratory facilities at Indian universities have declined instead of keeping updated. The advent of cost effective personal computers have made some impact in modeling and simulation of experiments but they are not substitutes for actual experiments.

In any experiment, several physical parameters are measured, under certain conditions. The experimental setup will have sensor elements to measure the parameters, control elements to alter them and recording/display subsystems to handle the generated data. Equipment for doing a specific experiment is made by selecting the required sensor/control elements and putting them together permanently in a specific way. Alternate method is to use a computer to integrate the sensor/control elements and manage them using software. This approach will reduce overall costs if the same setup can be configured for doing different experiments. Once the interfacing hardware and software are in place, one can connect any sensor element to it and take the measurements through software. Storage and analysis of data also becomes easier and more flexible.

Phoenix is a modular, extensible and cost effective hardware plus software framework for developing computer interfaced science experiments. Coupled with a computer, it can effectively replace a large number of equipment and enable one to carry out a variety of experiments using the same inexpensive hardware, of course by using different sensor elements and software. Phoenix enables students and teachers to design new experiments or to demonstrate various scientific principles, without getting into the details of electronics or computer programming. The power of personal computers has been effectively utilized for experiment control, data acquisition and mathematical analysis of data, with the help of simple and modular software. The system supports experiments at different levels of complexity. The following paragraphs describe the architecture, present status and several experiments performed using Phoenix.

A photograph of the basic hardware unit is shown in figure 1. The sockets on the top panel of the Phoenix interface box acts as gateways between
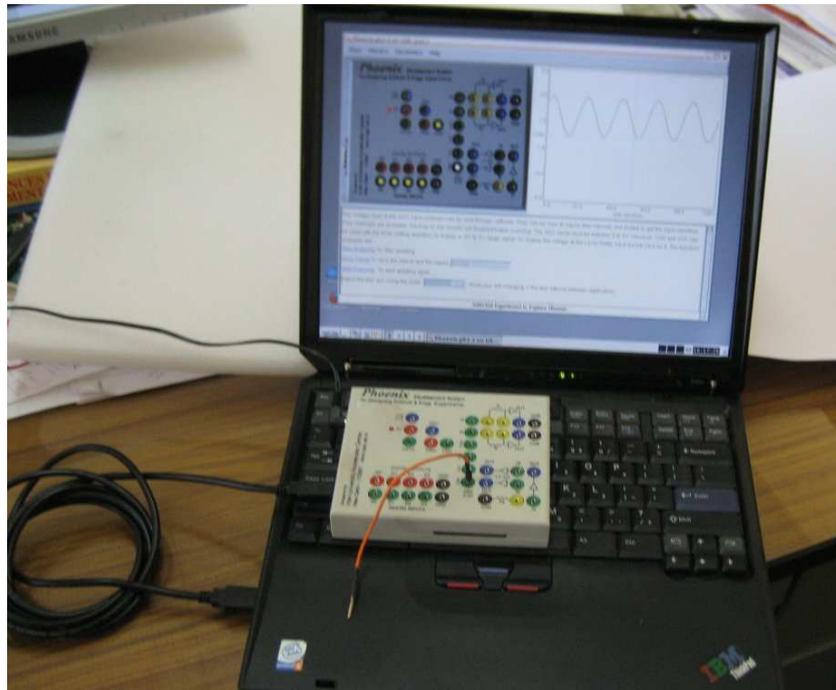
Figure 1: A Photograph of the Phoenix connected to laptop PC. The Phoenix hardware is placed on the PC keyboard and connected to the USB port. A small piece of wire is connected to one of the analog inputs of Phoenix. This piece of wire acts as an antenna and the AC mains signal picked up is continuously plotted by the software, phoenix is functioning here like a low frequency oscilloscope.

the computer and the outside world. Voltage levels at the sockets can be controlled/monitored, as a function of time, issuing simple commands or using a graphical user interface . Experiments are conducted by connecting appropriate control/sensor elements to the sockets and managing the overall operation under software control. Phoenix has been designed to cater to different levels of sophistication, using a modular design in both hardware and software. For example, it can do a simple experiment like capturing the voltage waveform induced across a coil, by a moving magnet, to a complex one like measuring the energy spectrum of alpha particles from a radioactive source. Details of the experiments done are given in the attached documents. [1,2,3].

Phoenix was developed at Inter-University Accelerator Centre, an autonomous research institute of University Grants Commission, India, providing particle accelerator based research facilities to the Universities.

2   Phoenix based Experiments

Science, a fundamentally open-ended and exploratory activity, is often taught as a collection of "facts" that many students get repelled from science, and most are deprived of an opportunity to strengthen and reinforce their own inclination

to experiment, question, and explore the outside world. Phoenix based experiments are exploratory and open ended. To illustrate this point, we take the example of an experiment to study electromagnetic induction.
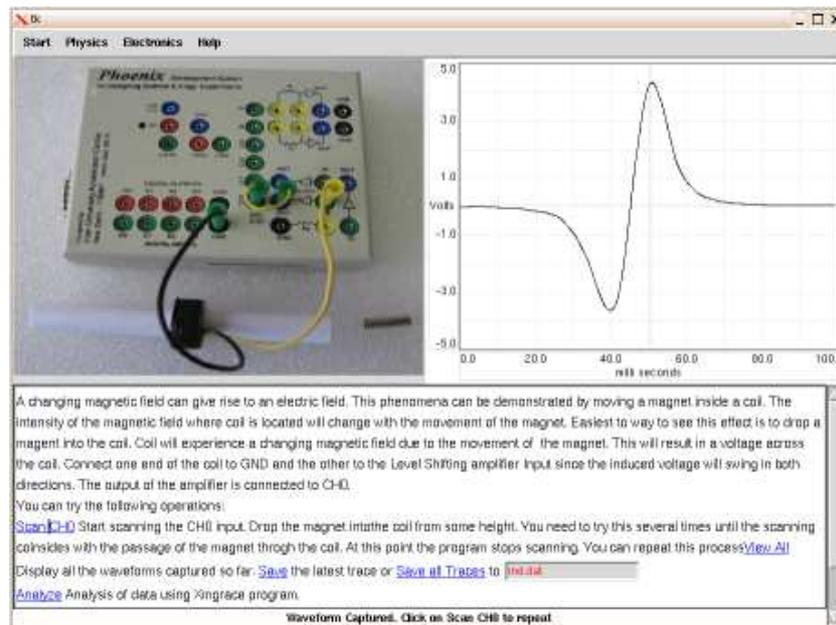
2.1   Electromagnetic Induction

Figure 2: Screen shot of the experiment to study electromagnetic induction. The voltage induced across a coil when a magnet is dropped through it is captured and plotted as a functions of time.

A voltage is induced across a conductor placed in a changing magnetic field. To explore this phenomenon, we have used a coil, having 5000 turns and about 1 cm diameter and length. The coil is connected between ground and one of the analog inputs of Phoenix. A magnet is dropped into the coil and the induced voltage waveform is captured as shown in figure 2. The voltage first develops in one direction, comes back to zero and then increases in the opposite direction. The objective of the experiment is to explain the curve obtained using theory of electromagnetic induction. The amplitude of the induced voltage depends on the velocity and strength of the magnet, dimensions and number of turns of the coil. The width of the waveform depends on the time taken by the magnet to pass through the coil. The theory should be able to predict the shape of the waveform obtained. We can alter the same experiment in several ways to explore various aspects.

- Drop the magnet from different heights to study the effect the velocity of the magnet on the waveform amplitude.

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- Use magnets having different length and observe the effect on the width and amplitude of the waveform.

- Estimate the velocity of the magnet from the distance between the two peaks of the waveform.

- Stop the magnet in the middle of the coil, to see whether one half of the waveform vanishes or not.

- Capture the waveform when a magnet kept inside the coil is suddenly removed. Is it unipolar or bipolar.

- Replace the magnet with another coil, powered by AC, to study mutual induction.

Apart from these variations, two such coils can be used as sensors to measure time of flight of a magnetic object. This can be employed in measuring acceleration due to gravity from time of flight. Generating the observed waveform using the relevant equations is a good theoretical exercise related to this experiment. A list of experiments conducted using Phoenix is listed in the next section.

2.2   List of Experiments

The number of experiments that can be done using Phoenix is decided by the sensor elements available. The physical parameters need to be converted into electrical signals, which is done by appropriate sensor elements. The sensor outputs are processed and connected to the input sockets of Phoenix. Some experiments in electricity and electronics can be carried out without using any sensors since they directly generate electrical signals. A list of experiments done using Phoenix are listed below. Details are given in the documents attached[2,3,4]

1. Capacitor

    (a) Exponential Charging/Discharging curves
    (b) Linear charging through constant current source
    (c) Measurement of capacitance
    (d) Measurement of dielectric constant of glass
    (e) Study of variation of dielectric constant with temperature

2. Electromagnetic Induction

    (a) Study of AC mains pickup and analyze the trace to estimate the frequency
    (b) Plot the voltage induced when a magnet is dropped into a coil
    (c) Study the effect of velocity, size and strength of the magnet on the voltage
    (d) Estimate the velocity from the shape of the induced waveform
    (e) Study of mutual induction using two coils and ferrite core

3. Study of Pendulum

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(a) Plotting of the damped sinusoidal waveform generated by a pendulum

(b) Waveforms generated by coupled pendulum

(c) Estimation of acceleration due to gravity from the period and length of the pendulum

(d) Accurate measurement of period using a light barrier made of photo-transistor

4. Study of Sound

(a) Direct measurement of velocity of sound in air, using a sound source and a microphone

(b) Study of reflection of sound using 40 KHz ultrasound piezo-electric transceiver

(c) Conversion of electrical signals into sound, creating music

(d) Digitization of sound and further analysis of it

5. Radiation Detection and analysis

(a) Energy spectrum of different α sources, using the radiation detection accessory of Phoenix

(b) Gamma counting using Geiger Muller tube connected to Phoenix

6. Study of electronic circuits

(a) Diode V-I characteristics curve, using the analog I/O sockets of Phoenix

(b) Integration of square wave to get a triangular wave and display both

(c) Study the RC integration by varying R, C and frequency

(d) Characterization of oscillator circuit outputs using Phoenix as a CRO, frequency counter and timer.

3   Awareness and Training Programs

In our present system, an experiment is included in the syllabus only if the equipment required is commercially available. Using Phoenix as a tool, we are trying to encourage teachers to design new experiments and include them in the syllabus at a later stage. This requires efforts to make the academic community aware of the new method and also to give them training and support. For this purpose, different types of programs are conducted by IUAC and also by several other organizations who find Phoenix interesting.

3.1   Programs by IUAC

IUAC provides support to organize *One Day Workshops on Phoenix* at Universities. They are meant for generating awareness and are generally attended by 50 to 100 physics students and teachers. The usage and implementation aspects are demonstrated and CDs were given to the participants for further information. So far IUAC have conducted around *25 One Day Workshops* at different

parts of India. Regular training programs are conducted at IUAC for physics teachers from colleges. During the Six Days Training Program, the participants are taught to perform experiments using Phoenix and how to use it for developing new experiments. They are also exposed to the computational techniques and software tools used for data analysis and numerical computation. Since the project is entirely based on Free Software tools, we are able to provide them the required software packages also. So far we have conducted 5 such programs, training around 80 teachers.

3.2 Experimental physics training programs by other organizations

There are several other organizations that found Phoenix a useful teaching aid and conducting training programs. West Bengal University of Technology has included Phoenix in their refresher course for physics teachers. Phoenix kits are also given to the participating teachers after the program. WBUT has conducted two such programs attended by around 50 teachers. Indian Physics Association, Kolkata chapter also are conducting training programs on Phoenix. Department of Education, Kerala, has initiated a pilot project to use Phoenix as a tool for IT-enabled education at high school level. They have obtained hundred Phoenix kits and started training the teachers. The experiments done by them are given in document *High School Phoenix* [2]. Freeduc-Science project, France, has shown some interest in this project. They have acquired the hardware and included the software in the resource CD prepared for school education.

3.3 Programs by engineering students

Phoenix is implemented using a micro-controller. At the same time it can act as a micro-controller development kit. This makes it a useful tool for implementing micro-controller based stand-alone projects. Equipment like frequency counter, temperature controller etc. has been made. This feature has attracted students from several engineering colleges and they have demonstrated Phoenix at various events like the annual Free Software conference FOSS.IN held at Bangalore, and other functions organized at NIT, Calicut etc. The Phoenix Wiki [6] has been setup by some engineering students.

4   Hardware & Software Implementation

To perform experiments and demonstrations using Phoenix, one need not know about its internal details. However, to design a new experiment one need to know how to connect a sensor to Phoenix and how to access it through software. The details of the Input/Output sockets on Phoenix are documented. Measurements on the signals connected to the socket are done through simple function calls. Python is chosen as the language, due to its simplicity and availability of huge libraries for scientific computation and graphics. A brief description of hardware and software are given below.
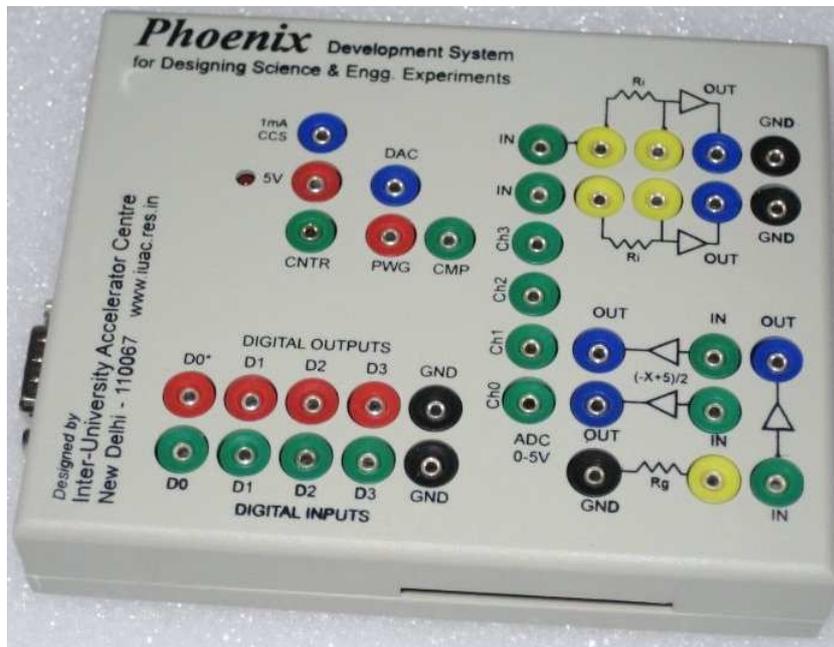
Figure 3: Photograph of Phoenix Interface. The front panel sockets having functions like Digital Input/Output, Analog Inputs (ADC), Analog Output (DAC), Waveform Generator, Frequency Counter, Op-Amp based gain blocks etc. are marked.

4.1 The Hardware

A photograph of Phoenix is shown in figure 3. The unit is powered by a 9V DC adapter. The hardware features are listed below.

- 10 bit resolution ADCs, 4 channels

- Digital Outputs, 4 channels

- Digital Inputs, 4 channels

- 8 bit DAC, 1 channel

- Frequency Counter, upto 1 MHz

- Square wave Generator, upto 4 MHz

- 1 mA Constant Current Source

- Variable gain Amplifiers

- 5V regulated DC output

- Serial/USB interface to Computer

The analog inputs can digitize 0 to 5V range signals into a number ranging from 0 to 1023. The minimum conversion time is 10 microseconds. The voltage

level changes at Digital Input/Output pins can be monitored/controlled with microsecond timing accuracy. The Analog output is implemented using a Pulse Width Modulated DAC having 8 bit accuracy. The control and sensor elements used in the experimental setup are connected to the I/O channels. The plug-in feature allows expanding the hardware capabilities. Since most of the sensor elements give small output voltages, variable gain Amplifiers are provided to make them into the 0 to 5V range before feeding to the ADC inputs. A 1 mA constant current source and a 5V regulated DC output also is provided.

4.1.1 Hardware Accessories

Most of the experiments require some extra circuits connected to Phoenix. For example measuring the period of a pendulum uses a photo-transistor circuit. Several such accessories have been developed and documented. Commercially available sensors for temperature, pressure, light etc. are used in making the accessories. Accessories were made to perform radiation detection and analysis using Phoenix. High resolution ADC plug-ins also were tested.

4.2 The Software

The role of the software is to communicate to the control/sensor elements of the experiment as per the instructions from the user. To make program development easier, we have followed a layered approach as outlined in the figure 4. The actual interaction with the hardware is done by the Firmware, written in C, running on the micro-controller, as per the commands from the PC. On the PC side a Python library provides a simple interface to the user programs that perform the experiments. Python is amazingly simple to learn with its clean syntax and already has a huge collection of library and programs for scientific computation. Python can be used either from inside the interpreter or by running the python programs stored in files. Using the graphics libraries available under Python, several GUI programs have been written for doing various experiments. Programs are also written to make Phoenix to function as a low frequency storage oscilloscope, frequency counter, function generator etc.

Even though the user can conduct several experiments using the GUI programs provided, designing new experiments require accessing the hardware accordingly. The hardware features can be accessed by calling the functions from the Python library, that are well documented. For example the AC mains pickup shown in figure 1 can also be generated by the few lines of code listed below

```
import phm        # Loads the phoenix library
p = phm.phm()     # Creates an object representing phoenix
p.select_adc(0)   # Select the first ADC channel
while 1:          # An infinite loop
    v = p.read_block(200, 500, 0)    # samples input voltage
    p.plot_data(v)                   # plots it
```

This program samples the voltage at the first analog input every 500 microseconds and plots the data after every 200 samples. Similarly there are functions for reading/controlling the voltage levels of Digital Input/Outputs and all other hardware features provided by Phoenix.
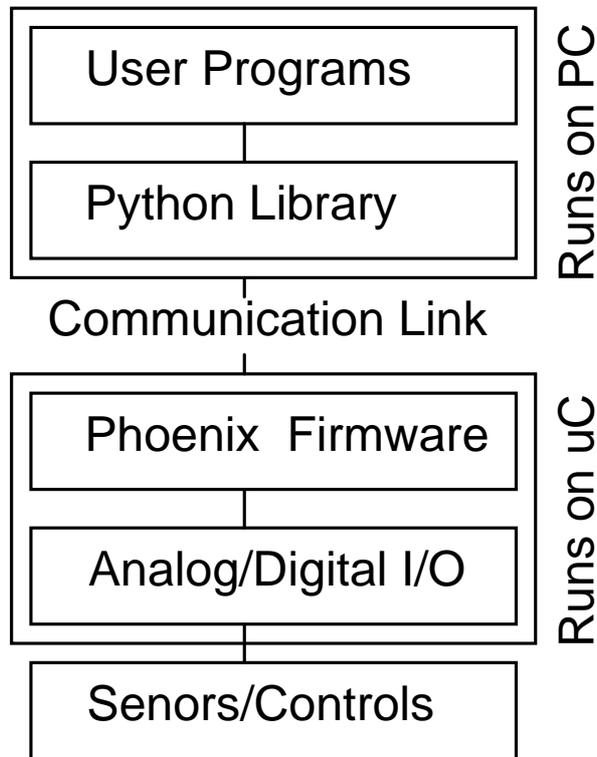
Figure 4: Schematic of the Software architecture of Phoenix. Actual measurements are done by the firmware running on the micro-controller located inside the Phoenix box. The firmware receives commands from the PC, through RS232/USB interface, and the results are send back. On the PC side, Python is chosen as the programming language due to its simplicity and availability of libraries for scientific computation and graphics.

5   Present Status

The project is now running into its third year and we are finding more and more people showing interest in it. The project is run in a community mode and is open to suggestions and contributions. The hardware details and source code of the software along with necessary documentation are kept on IUAC website. Information about Phoenix and communication regarding it are conducted mainly through the following channels

- IUAC website (www.iuac.res.in).

- The mailing list address phoenix-project@freelists.org

- The wiki http://electronics.wikia.com/wiki/PHOENIX

- The Phoenix Live CD, containing Phoenix software and documentation along with GNU/Linux operating system.

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So far around 250 units have been sold by different vendors. Some universities have started using it for doing student projects and are also considering inclusion of phoenix based experiments in the syllabus. More and more experiments are being developed.

5.1   Cost and Availability

One of the major advantages of Phoenix is the low cost. Since the development costs are absorbed by IUAC, the price of the product is mainly decided by the raw material and assembling charges. The commercial production is allowed without any license or royalty requirements. Currently there are vendors at Delhi, Kolkata and Kerala who are assembling the units. Availability from multiple vendors keeps the cost reasonable. *At present the basic unit is commercially available for Rs.1500/- .* (details are given on the website). The software is developed entirely using Free Software tools and distributed under the same license.

6   Conclusion

A new method to make low cost equipment for science experiments have been successfully implemented. It is found to be a potential tool for inquiry based education, due to the flexibility provided by software. A wide range of experiments with varying degrees of complexity has been done. We are gradually building a user community with active participation from a lot of people. Present feedback suggests that this has the potential to improve the science education.

References

[1] Innovative Science Experiments using Phoenix, by Ajith Kumar B.P., V.V.V. Satyanarayana & Kundan Singh, Physics Education journal, Vol 24 Jul-Aug 2007

[2] High School Phoenix , by Ajith Kumar B.P.

[3] A method to improve experimental facilities for teaching nuclear physics, by Ajith Kumar

[4] Innovative Experiments using Phoenix, by Ajith Kumar B.P. and Pramode C.E.

[5] http://www.iuac.res.in

[6] wiki http://electronics.wikia.com/wiki/PHOENIX