The development of a Microcomputer-Based Laboratory (MBL) system for gas pressure law experiment via open source software

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ABSTRACT

The purpose of this research was to develop a Microcomputer-Based Laboratory (MBL) system for gas pressure law experiment used in physics education. The developed system was divided into two major parts; the hardware and courseware. The main hardware of the system was the PHOENIX (Data Logger) which was obtained from Inter-University Accelerator Centre (IUAC), New Delhi. Others hardware used were temperature sensor and pressure sensor. These hardware components were controlled by a computer. The sensors were calibrated according to the standard reference of pressure and temperature. The data and parameters obtained from the calibration were used in the courseware to determine the pressure and temperature based on the voltage of the sensors. While the courseware part was developed to execute data logging, data processing and display the real-time plot on the computer screen. The courseware design for this system was developed based on the Analysis, Design, Development, Implementation, and Evaluation (ADDIE) instructional model, while the courseware programming was written by using the Python Programming Language (one of the Open Source Software Systems). Thus, this low cost developed package can be used as laboratory exercise and demonstration kit for teaching and learning process.

Keywords: Microcomputer-Based Laboratory, Gas Pressure Law Experiment, Physics Education, Open Source Software, Courseware Development.

INTRODUCTION

Generally, the MBL system can be divided into two major parts; hardware and courseware. The hardware part consists of data logger and various types of sensors. The courseware part is to execute data logging, data processing and display the real-time plot on the computer screen.

Scientists need experiments to verify theories. For students, they need to do the experiments in order to understand the theories. So, the experimental exercises are very important in learning physics. MBL system is one of the practical approaches to run the experiments. However, the MBL hardware and software in the market are very expensive for school, matriculation, college and university laboratories in Malaysia.

For the thermodynamics course, there are many experiments which require the use of thermometers and bourdon gauges. Additionally, the students need to take both readings at same time. Therefore, this manual data collection will produce errors. So, it is totally different if the students use the MBL system. The MBL system enables the user to gather both data simultaneously. For these reasons, researcher developed a low-cost MBL system using a data logger incorporated with the temperature and pressure sensors. The courseware program for controlling the system was written by using the Python Programming Language version *2.4.3* (one of the Open Source Software Systems).

RESEARCH BACKGROUND

Conventional practical exercises in learning Physics normally require students to follow specific procedures and solve specific questions provided in the laboratory manual. Hence, longer period of time is used to conduct these routines of recording the data manually, plot the graph and doing the data analysis.

In the MBL system, all routine jobs are computerised and therefore save the time for other activities. The MBL activities can be programmed as to encourage students to create questions and solve the problems themselves, instead of depending on the limited scope of the questions provided in the laboratory manual (Krajcik and Layman, 1993).

To use the MBL system, the students need to fix or probe sensors to a system. The probe is attached to a computer, where it provides utility for students to access the instruction and information displayed. Students will have the opportunity to perform a real experiment and compare to simulation experiment. Hence, they will gain new learning experience in performing experiment by using the MBL system. Students will be able to collect and record data and then plot the graph immediately on the monitor screen of the computer.

Since the MBL activities can be diversified, the teachers who develop the experiments will also increase the knowledge and creativity in developing new experiments. As Steinberg (2003) claimed, "science teachers who progressively upgraded the MBL technique, which could attract students' attraction, would have the opportunities to engage students intellectually, to explore more meaningful and exciting subject matter".

Generally, the cost for the MBL system development and the use of the MBL apparatus is relatively higher than the cost for the conventional manual system. The cost will be even higher if the system is to be applied in all stages of education (Gintautas and Hubler, 2009; Ajith Kumar, 2008). In order to make it possible for the MBL system to be used in education, the cost must be cut down. A group of workers from the Inter-University Accelerator Centre (IUAC) had taken up this task. They developed the PHOENIX Development System for Designing Science Experiments. This hardware package was cheap enough for college level or even school laboratories to own and enabling them to do experiments and performed numerical analysis of the data using computers (Ajith Kumar, 2008). To make it cheaper, the software development for package uses the Python Programming Language from the Open Source Software (OSS) system.

PROBLEM STATEMENT

The annoyances of errors in scientific experiments are unavoidable but the errors can be reduced. In the conventional experiment for thermodynamics, there are two types of errors. The first type is the random errors which are due to incorrect eye position of the observer or incorrect instrument when making measurement. The second type is the systematic errors which are due to the error in calibration of instrument or imperfect methods of observation (Northrop, 2005). The students will find out the overall errors after comparing the experimental result with theoretical result. The students will have to repeat the whole process of the experiment in order to have more precise result.

For example, *Figure 1* shows the Pressure Law experiment for secondary school in Malaysia (Chang, Koay Kheng Chuan & Yew Kok Leh, 2007). The aim of the experiment is to investigate the relationship between the pressure and temperature of gas when volume is constant. However, the thermometer measures the temperature of water. This will generate the systematic error. While reading the data from the thermometer or bounder gauge, the students may get incorrect data due to incorrect eye position (random error). Additionally, they need to gather both readings; the temperature and pressure simultaneously.
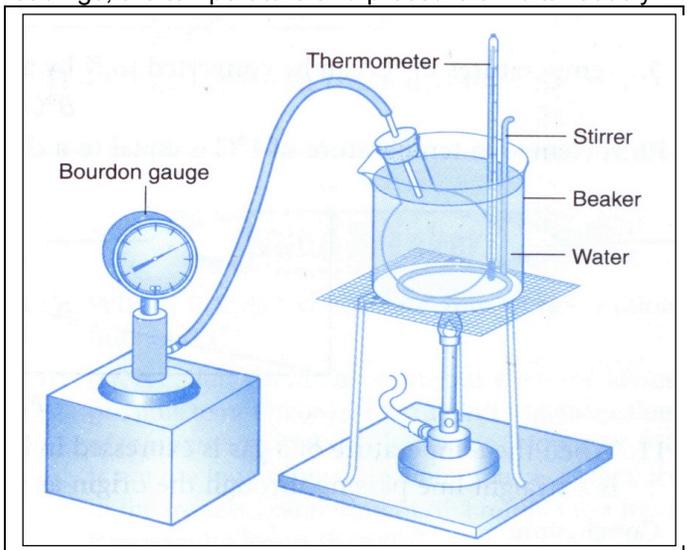
Figure 1: Conventional Pressure Law Experimental Setup

The MBL system can overcome the difficulties faced in the conventional way of performing the gas pressure law experiment. The random errors can be reduced because the data are recorded by temperature and pressure sensors. The systematic error is corrected because these sensors are placed in the gas system. Nevertheless, the standard MBL system and apparatus available in the market are foreign products and they are expensive (Taylor, 1997; Ajith Kumar, 2008; Gintautas and Hubler, 2009). The software to run the experiments remains the property of the manufacturer and cannot be accessed. So, the application cannot be diversified. The component parts and servicing are all depending on the manufacturer alone which causes delay and high maintenance cost.

OBJECTIVES OF THE STUDY

- To develop an open source-based gas pressure law experiment incorporating the technology of PHOENIX (IUAC), pressure sensor and temperature sensor.
- To design the experimental set for Gas Pressure Law Experiment.
- To validate the experimental set for Gas Pressure Law Experiment

METHODOLOGY

The study of Gas Pressure Law in a gas system requires measurements of pressure and temperature at constant volume. Conventionally, those quantities are observed and recorded manually. In this research, the quantities were recorded by the sensors which were interfaced to

a computer. The data collected by the sensors were transmitted to the computer for analysis. This interfacing involved the development of courseware which enabled the data to communicate between the sensors and the computer. Generally, the procedure for the development of this experimental apparatus system was divided into three areas, namely the calibration of the sensors, the development of courseware interfacing, and the development of the hardware components of the apparatus. The procedure of research methodology was summarised in the block form as shown in *Figure 2*.

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┌─────────────────────────────────────────┐
│   ┌─────────────────────────────────┐    │
│   │      Calibration of Sensors     │    │
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│   │      Courseware Development     │    │
│   └─────────────────────────────────┘    │
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│   │   Experimental Set Development  │    │
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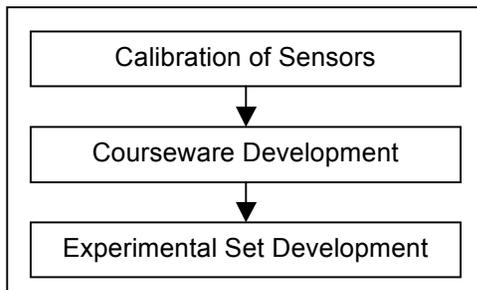
Figure 2: Procedure of Research Design

CALIBRATION OF SENSORS

The functions of the sensors were to detect the physical quantities giving an electrical voltage output. This voltage output required to be calibrated to a specific quantity. In this work, the specific quantities recorded were the pressure and temperature.

The Phidgets pressure sensor measures the gas pressure and the unit used was the kilo Pascal (kPa). The PT100 temperature sensor measures the temperature and the unit is the Degree Celsius (^{o}C). Therefore, the voltage outputs of the sensors were converted into their respective quantities by the equation formulated from the observation by comparing with certain standard references. Schematically, the calibration procedure was summarised in the block form as shown in *Figure 3*.
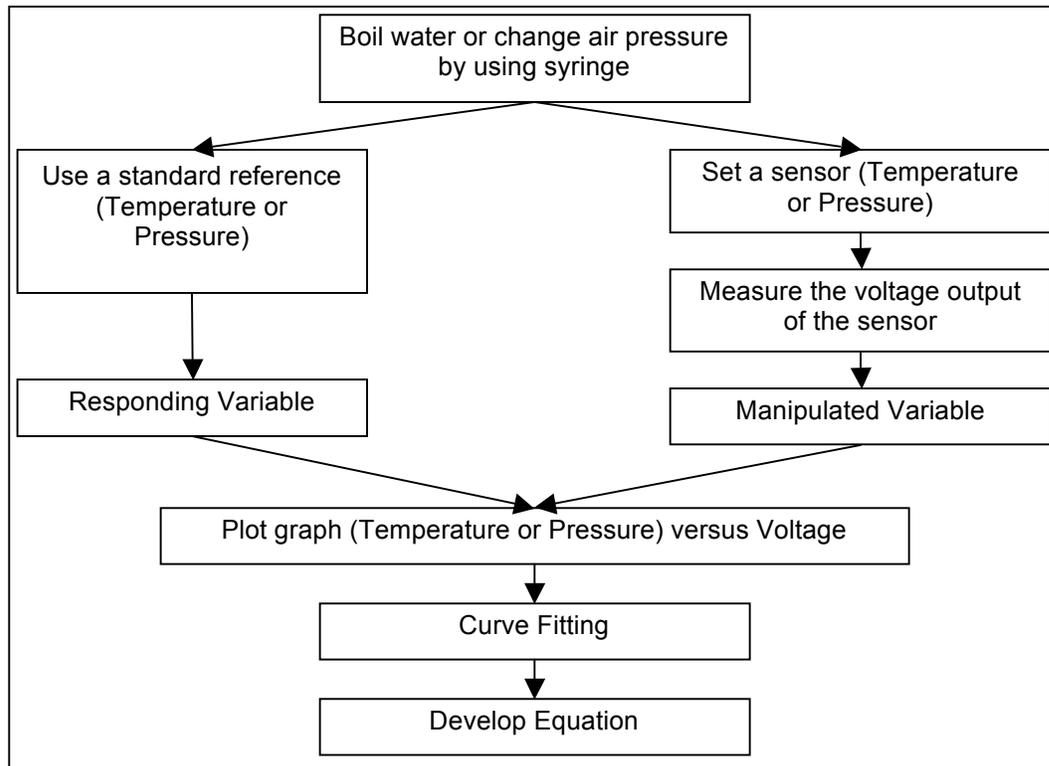
Figure 3: Procedures for Calibration of Temperature and Pressure Sensors

COURSEWARE DEVELOPMENT

In this research, the ADDIE model was chosen. Recently, ADDIE model was established as industry standard for instructional design of educational media (Trollinger, 2001). From this current report, it was found to be convincingly simple to adapt the elements of the ADDIE instructional design model in the development of courseware programming for the MBL apparatus system. There are five phases in ADDIE model – Analysis, Design, Development, Implementation, and Evaluation.

Analysis Phase

MBL system (hardware and courseware) that could be applied for physics education was developed. The preliminary criteria of the design for MBL system must be low cost and should be simple to operate.

Design Phase

The information of the hardware components were gathered from the internet and electronic catalogue. The low cost of the PT100 temperature sensor was obtained from the RS Components Company while the pressure sensor was obtained from Phidgets Company. Both of the sensors were essential for the MBL system in gas pressure law experiment.

The experimental system to be developed was to study the gas pressure law. The main reference hardware for this development was the PHOENIX Development System (Data Logger) from Inter-University Accelerator Centre (IUAC), New Delhi. The operation of the experimental system was divided into three stages; INPUT, PROCESS and OUTPUT (IPO). **Figure 4** shows schematically the sequence of the IPO for experimental system.

Input Pressure and Temperature sensor.	▶	**Process** Real-time gas law experiment using MBL system.	▶	**Output** Pressure-Time and Temperature-Time Graphs.
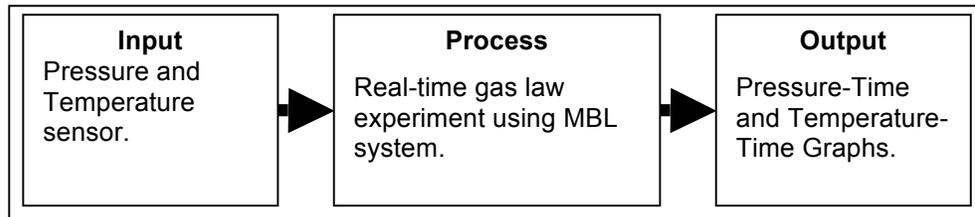
Figure 4: *Schematic Flow for the Input-Process-Output for Experimental System*

The user interface of the courseware program was designed. This courseware was found to be user friendly because it provided the user visual interaction with the computer. There were many User Interface (UI) toolkits from python programming language such as Tkinter (Tk), Tix, Pmw, wxPython and PyGTK. For the work in this project, the Tkinter (Tk) toolkit was used. Tk was the primary and most popular UI toolkit for the Python Programming. For programming the UI in this courseware development, 7 types of widget from Tk Widgets were used; button, canvas, frame, label, message, scale and text.

In the design phase, the flowchart of the courseware operation was an important element. At the beginning, a START box was selected. The inputs were the pressure and temperature. These inputs were processed by a PHOENIX data logger. Then, the real time data was plotted in the form of graphs (output). The time intervals between 2 plots were set to 5 seconds. It is because the data logger could be easily record readings for very small time intervals (much less than a second). In fact, it was easy to acquire too much data, which could complicate the data selection or analysis. Therefore, 5 seconds of time intervals was chosen (20 minutes or 240 readings). After that, the file was renamed and saved into the containing folder (MBL folder). The graph was printed by using printer. If there was no printer connected, the graph was saved as image namely pre_temp.gif in the MBL folder. Therefore, the flowchart of the courseware operation was shown in the **Figure 5**.
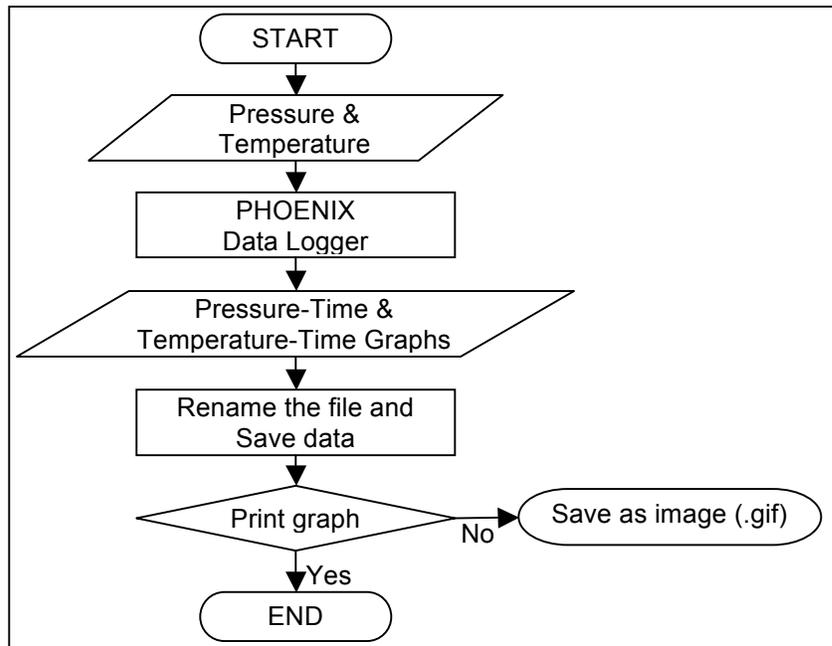
Figure 5: Flowchart of the Courseware Operation

Development Phase

After the development of the experimental system was completed, the system was run on different computers to test its versatility for use in different computer environment. The debugging procedures and solutions to those problems in a different computer environment were performed.

Implementation Phase

A procedure or guideline for using this MBL built system was developed. The guideline covered the installation of courseware, laboratory manual, circuit connection, and testing procedures. Preparation of the learners included training them on new tools (courseware or hardware) and student registration. Additionally, this was also the phase where the researcher ensured that the user's manual, laboratory manual, tools (sensors and PHOENIX data logger) and all the courseware and hardware were in good condition.

Evaluation Phase

The evaluation phase was a part of the continuing the development of the courseware. So, it was important to perform the evaluation. While performing the evaluation, the review and evaluation of each phase (analyze, design, develop, implement) were done to ensure that it was accomplishing what it was supposed to. Once the data and feedback were collected, some changes were made for the system improvement.

EXPERIMENTAL SET DEVELOPMENT

For experimental apparatus development, the experimental set based on the Gas Pressure Law (Gay-Lussac's Law) was developed. Therefore, all the design involved must solve the conventional experiment problem. In addition, the development consisted of the design of the apparatus of the experiment and the laboratory manual as the instruction or guideline for student who wanted to conduct the experiment.

Conventionally, gas pressure law experiment was carried out by using the bourdon gauge and the mercury thermometer. The bourdon gauge was attached to a cavity enclosing dry air and it was submerged in water. But, the mercury thermometer was attached to the water. As the dry air was heated, the thermodynamics state changed. However, the manual technique of measuring pressure and temperature provided large uncertainty. In the new design, the sensors measured directly the pressure and the temperature of the dry air system trapped in the Erlenmeyer flask. The temperature sensor was dipped into the dry air system through sealed stopper (see ***Figure 6***).
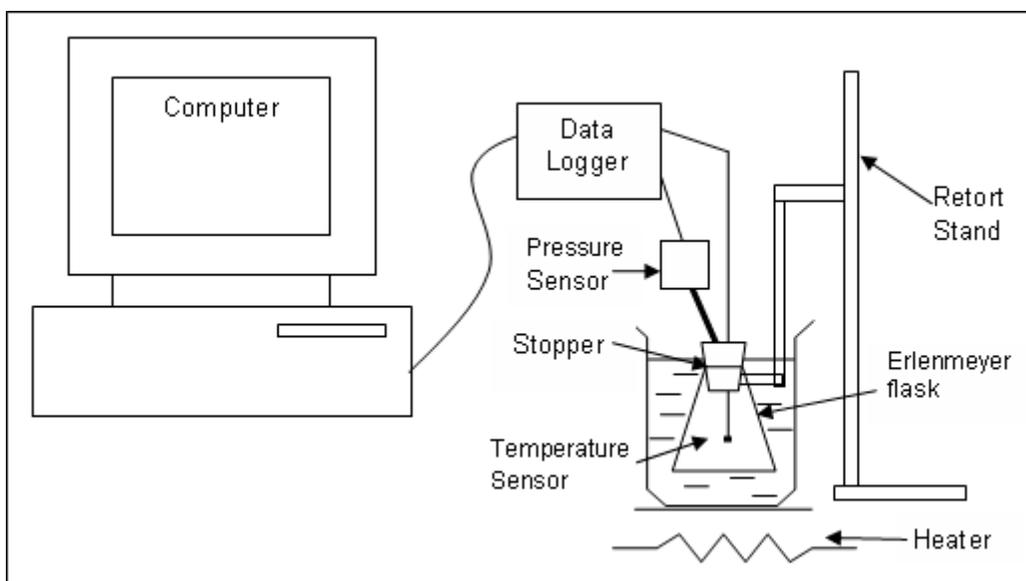
Figure 6: *Gas Pressure (Gay-Lussac's) Law Experiment*

RESULTS

This section described the results obtained from the MBL built system. It is organized into two subsections: first, substitution of the equation obtained from calibration into courseware package and presentation of developed courseware; Second, presentation of the Gas Pressure Law experimental results.

Result of the Developed MBL Courseware

From the result of the calibration, the data and parameters of the equations from the calibration of the sensors were substituted into the courseware program. The courseware routine to execute the program was shown in the ***Figure 7***). Thus, the user interface of courseware had successfully developed using Python Programming Language.

```
from Tkinter import *
import phm, time, Image, ImageTk, ImageDraw
import helptho, drawtho

def v2p(y):                    # Calibration for Phidgets Pressure Sensor
    m = 49.9
    c = 8.46
    y = y * 0.001
    p = m*y + c
    return p

def v2t(j):                    # Calibration for PT100 Temperature Sensor
    m = 105.0
    c = -242.0
    j = j * 0.001
    t = (m*j + c)
    return t

def update():                                      # Start the sensor
        global data, running, timegap, ph, pressure, temp
        if running == False:
                return
        for ch in range(2):
                ph.select_adc(0)
                res = ph.get_voltage()
                x = res[0] - starts[0]          # Time
                y = res[1]
                p = v2p(y)                          # Convert voltage to pressure
                data[0].append((x,p))
                if len(data[0]) > 1:
                        dispobjects[0].delete_lines()
                        dispobjects[0].line(data[0], 'black')
                ph.select_adc(1)
                res = ph.get_voltage()
                i = res[0] - starts[1]          # Time
                j = res[1]
                t = v2t(j)                          # Convert voltage to temperature
                data[1].append((i,t))
                if len(data[1]) > 1:
                        dispobjects[1].delete_lines()
                        dispobjects[1].line(data[1], 'black')

        if x > 10800:
                print 'done'
        else:
                root.after(timegap, update)
```

Figure 7: Courseware routine to execute the program

Once the pressure law experimental setup was completed, the experiment was run. Then, the MBL icon was clicked. The window was shown in *Figure 8*. The 'START' button of the courseware was clicked, and then the graph was plotted automatically for every 5 seconds. Subsequently, the 'STOP' button was pressed once the temperature access around 75°C (Temperature data display). After that, the save file was renamed (for example pre_temp1.dat). The data was saved once the 'SAVE to' button was clicked. The entire file saved in the containing folder which was the MBL folder. Furthermore, the explanation for all the buttons was shown on *Figure 9*. It would be useful for those want to use this courseware.
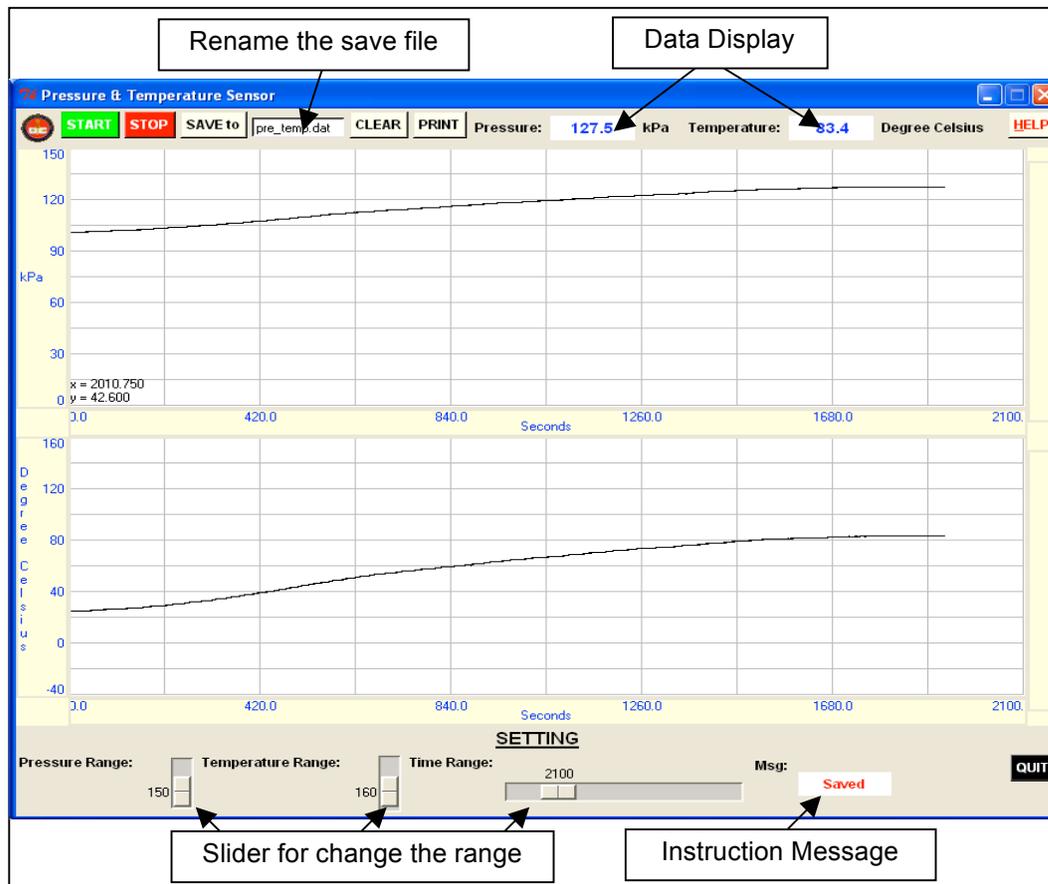
Figure 8: *The Computer Window Display the Output Result*
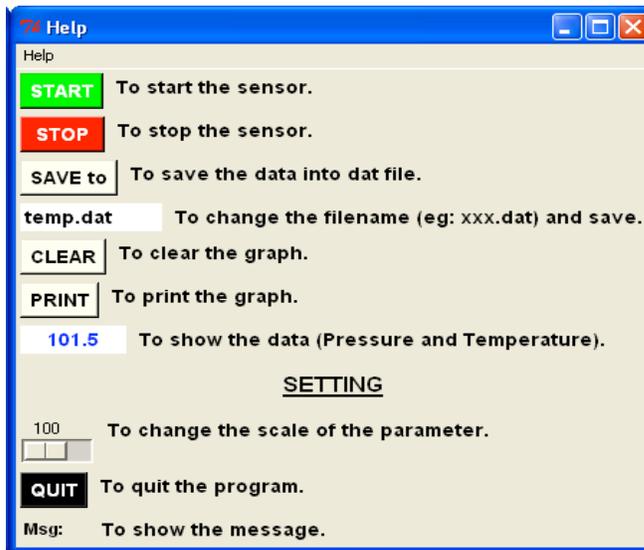
Figure 9: *Help Menu to Explain the Function of the Buttons*
Gas Pressure Law Experimental Results

The data was further analysed using the Microsoft Excel (see **Figure 10**). A graph of pressure against temperature was plotted and linear graph was obtained. When extrapolated, pressure *P* = 0 occurred at where the gas temperature was called as absolute temperature (absolute zero Kelvin, -273.15^{o}C).
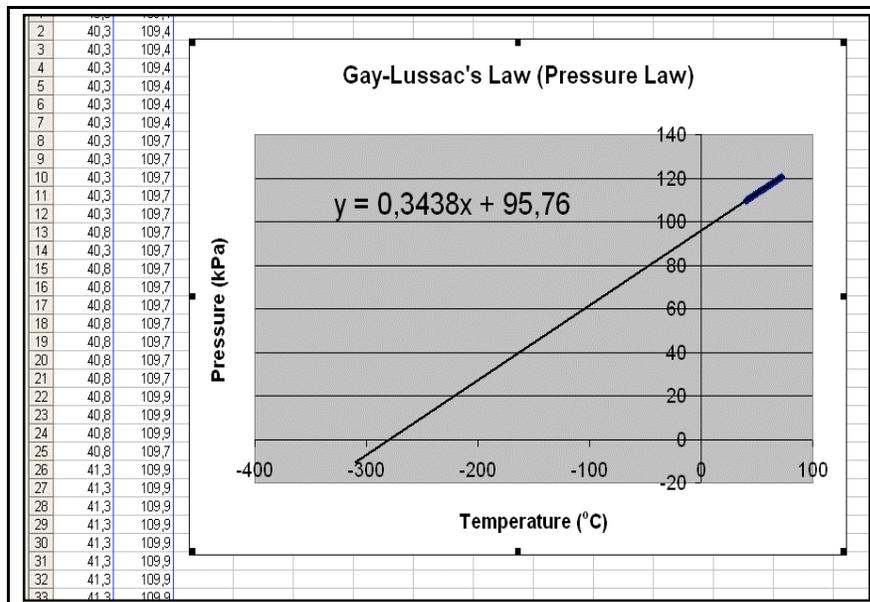
Figure 10: *Graph of Pressure against Temperature for the Gas Pressure Law System*

From the equation obtained, the absolute temperature of the pressure law experiment was calculated as shown in **Table 1**. From the analysis of the results, the averages of the absolute

temperature obtained from the experiment results were equal to -271.16^{o}C. Therefore, the average percentage error of the pressure law experiment was equal to 2.04%. Thus, the percentage error obtained from theory of the absolute temperature was within the range of ± 5%.

Table 1: *Result Absolute Temperature in Pressure Law Experiments*

Experiment	Absolute Temperature (^{o}C)	Percentage Error (%)
1	-278.53	1.97
2	-270.10	1.12
3	-264.85	3.04
Average	-271.16	2.04

DISCUSSION

Gas pressure law experiment for tertiary physics education based on open source programming language was developed at Physics Department, UPSI. The developed system was divided into two major parts; the hardware and courseware. The hardware consisted of a PT100 temperature sensor, a pressure sensor and the pressure law experimental apparatus. The courseware part was developed to execute data logging, data processing and display the real-time plot on the computer screen. Thus, this low cost developed package could be used as laboratory exercise and demonstration kit for teaching and learning process.

This product was developed to solve two major problems. Firstly, the pressure law experiment conducted using this experimental apparatus produced result with small percentage error which was in the range of 5%. Secondly, the cost of the data logger system would be reduced. The courseware was developed using one of the open-source software known as Python programming language. Additionally, the low cost pressure and temperature sensors were used in this system. Thus, this simplified product could be used to replace the conventional pressure law experiment due to the low-cost system, computerized, easy setup and smaller error.

CONCLUSION

A MBL apparatus for the study of gas pressure law in physics courses taught in school and university had been successfully developed. It is hoped that this MBL system will be able to use for the physics laboratory exercises in UPSI. It is also hoped that this system can be expanded for other science laboratory courses.

One of the purposes of the laboratory exercises is to support the students to understand lecture or class discussion. This MBL system provides simplicity in doing the experiment. Once the apparatus has been set, the only requirement is to press the start button on the menu panel and the following procedures will be automatically extended. Using this MBL apparatus for the study of pressure law of a gas system, students will be able to observe the variation of pressure as the temperature increase. These changing parameters are recorded and shown graphically on the computer screen. At the end of the experiment, the data, graph and result can be printed out in the form of hardcopy. The data could be further analysed using the Open Office spreadsheet or the Microsoft Excel.

This technique replaced the conventional method where students have to spend more time on manual data recording and graph plotting. The data obtained from this developed MBL system produced result with high accuracy. The average absolute zero Kelvin calculated from the Gay-Lussac's Law (Pressure Law) experimental data was -271.16^{o}C, which was closed to the

theoretical absolute zero Kelvin (-273.15°C). The deviation of the experimental result was within the range of ± 5% from the theoretical value. The theoretical value was calculated based on the ideal gas system. In this experiment, the sample used was the dry air. Dry air is real gas which only possesses the characteristics of an ideal gas at high temperature. Hence, the discrepancy of 5% from the theoretical value is acceptable for the educational motive to explain the behaviour of the gas system.

ACKNOWLEDGMENTS

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