Use of Computer-Based Data Acquisition to Teach Physics Laboratories: Case Study- Simple Harmonic Motion

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Abstract. *Several experiments and demonstrations using computer-based data acquisition systems have been developed in our physics laboratory. These computer applications enable students to collect, display and analyse data in real-time. They also enhance the learning process by helping students visualize and understand the relationship between the theory and the observed behaviour in an easy and intuitive way.*

In this paper, we describe the real-time laboratory experiment of Simple harmonic Motion that we have developed which employs computer-based pedagogical tools. In particular, we demonstrate how computers can actively interface with experiments, rather than simply play a passive role in data acquisition and analysis. We also discuss the interaction between students and the instructor.

Keywords. Simple harmonic motion, Computer based laboratory, Amplitude, Displacement, Velocity, Acceleration.

1. Introduction

Laboratory experiments play a fundamental role in teaching and learning physics. Computer-based laboratory, CBL, experiments and demonstrations have been used to collect and analyse data measurements, to provide graphic representations, and to fit data with functions suggested by the adopted model. CBL experiments have been successfully implemented for many years in science and technology colleges, as reported elsewhere in literature [1-3].

Several CBL experiments and demonstrations in physics have been developed and implemented at our institution, École de Technologie Supérieure (ÉTS). Appropriate sensors, interfaces and software have been used to produce an effective data acquisition system for collection, analysis and display of experimental data [4]. Students doing experiments can examine the display of their results and graphs in real-time. Thus the interpretation of data is done in a reasonably short time-frame. The main finding from various aspects of CBL implementation in educational laboratory settings is that students and instructors have a high level of motivation and gain more control over the curriculum. The CBL hands-on experiment enhances students' learning by allowing them to perceive relationships between independent and dependent variable parameters as soon as it is finished.

The exploration with real-time measurements gives students feedback and comprehension of the subject by presenting data graphically. It also enables them to predict relationships between variables and to verify the nature of these relationships [5-6]. By using hardware (sensors, interfaces and accessories) and software students can simultaneously measure and graph physically quantities such as force, temperature, pressure, volume position, velocity, acceleration. These tools are found to be effective in teaching science and technology and can provide a mechanism to deal with conceptual difficulties**.** The proposed lab experiments are closely related to the lecture topics of the physics curriculum**.** The experiments are performed by small groups (three to four-person teams) using the implemented laboratory reservation system to book an experiment session. This schedule system facilitates users' request at different priority levels, such as scheduling laboratory rooms, selection of number of experimental setup in each laboratory, cancellation of any scheduled laboratory session, book any scheduled laboratory experiment. This laboratory scheduling system was integrated in to the department in order to optimise the efficiency of learning sciences.

The CBL experiments and demonstrations were using personal computers, interfaces, hardware and software produced by *PASCO Scientific* [7].

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Hardware consists of sensors for detecting movements, sound waves, pressure, temperature, and electrical signals, as well as signal generating components, including an amplifier that can provide external laboratory equipment with digital or analog signals. The software (*Science workshop Datastudio*) allows the user to collect the data, calculations, and data displays, to analyse results, to compare relationships, and to present conclusions.

To illustrate the importance of computer based laboratory (CBL) in physics education**,** we present below a practical work based on real time experiment of the displacement of vertical mass-spring oscillating in simple harmonic motion. This work was carried out by instructor and students.

2. Simple Harmonic Motion (SHM) practical work

One of the topics in physics laboratory courses which can help students to learn from the use of CBL systems is the simple harmonic motion taught in mechanics and waves course. The oscillatory motion is very important to evaluate time evolution, displacement from the equilibrium position, velocity, acceleration and phase of oscillation of a mass attached to a spring. The system under investigation is the analysis of vertical simple harmonic motion (SHM), as shown in Figure 1. The components of the experimental arrangement are: a rod, a rod base, a mass of 200g, a spring, a motion sensor, a *science Workshop 750* Interface and a laptop. The motion sensor measures the position of the oscillating mass as a function of time.

Students have to analyze a vertical mass-spring oscillating in simple harmonic motion, which is described by

$$x(t)=A\cos(\omega t+\varphi), \quad (1)$$

where $x(t)$ is the displacement position of the mass at time t from the equilibrium position ($-A \leq x \leq A$), A is the amplitude of oscillation, ω is the angular frequency, $\omega = \sqrt{\frac{k}{m}} = \frac{2\pi}{T}$ T is the period of oscillation, and φ is the initial phase ($0 \leq \varphi \leq 2\pi$) which corresponds to x and v at $t = 0$.

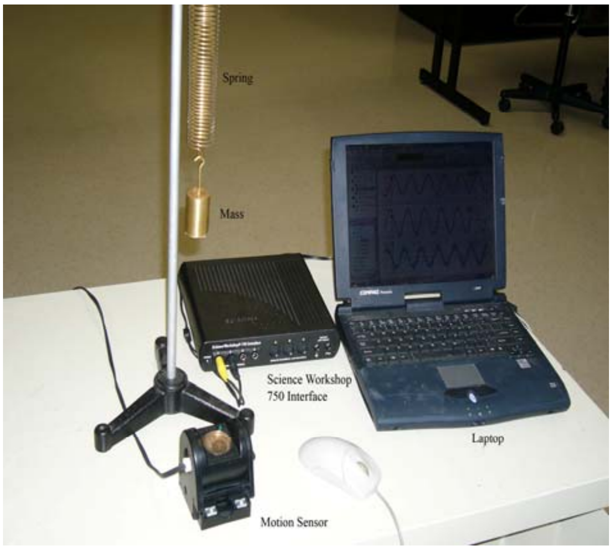

Figure 1. Experimental setup of mass-spring oscillator.

2.1. Analysis of the displacement position in SHM

In order to verify the movement of a vertical mass-spring oscillator, Eq. (1), students carry out the following steps:

1. Measuring the amplitude (A) and the period (T) from the graph displacement as a function of time, Figure 2, and calculate the angular frequency (ω). The obtained results are summarized in Table 1.

Table 1. Results of measurements

Height (m)	0.403 0.243
Period (S)	1.101
Offset	0.323
Position (X)	+0.08 -0.08
Amplitude	0.08
Angular frequency ω (rad/s)	5.70654

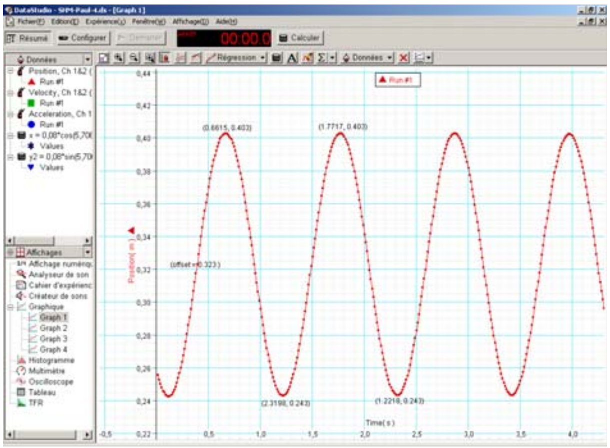

Figure 2. Position as a function of time of mass-spring oscillator.

2. Evaluating mathematically the initial phase (φ) using the position (x) from equilibrium and the velocity (v) at time t > 0. The graph representing the velocity as a function of time is illustrated in Figure 3. The values of position (x) and velocity (v) which were taken from the graphs position and velocity as a function of time were

Graph *x (t)*: at t = 1.0694 s, the position x = -0.053 m

Graph *v (t)*: at t = 1.0694 s, the measured velocity v = -0.34 m/s

Equations *x (t)* and *v (t)* at time t = 1.0694 s are as follows:

$$x(t{=}1.0694s)=A\cos(5.70654*1.0694+\varphi) =-0.053m \qquad (2)$$

$$v(t{=}1.0694s)=-5.70654A\sin(5.70654*1.0694+\varphi) =-0.34m \qquad (3)$$

Dividing Eq. (2) by Eq. (1) we obtain $tg(6.10257+\varphi)=-1.12417 \Rightarrow tg(\alpha)=-1.12417$ (4)

Where, $\alpha = tg^{-1}(1.012417) = -0.843785$ or $\pi - 0.843785 = 2.29781$

The choice of α depends on the sign of cos α or sin α. Since cos α is negative and sin α is positive, then α = 2.29781 and the value φ = 2.47842 is chosen, because it corresponds to the conditions of position and velocity at the chosen instant time t. The equation, $x(t) = 0.08 * \cos(5.70654 * t + 2.47842)$ which describes the displacement from the equilibrium position is entered into the calculator of *Science Workshop* software.

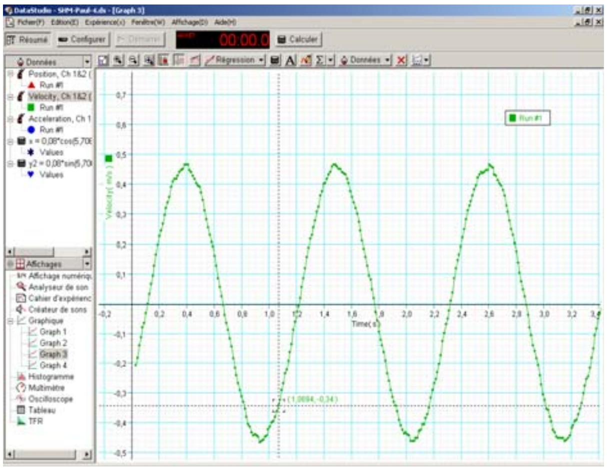

Figure 3. Velocity as a function of time of mass-spring oscillator.

The plot of this equation is displayed in the same window of the graph position as a function of time, as shown in Figure 4. The plot at the top of Figure 4 represents the measured position and the lower one is the graph obtained by calculation. The calculated and measured displacement position equations for vertical mass-spring were compared. One can notice immediately from the results these two periodic shapes of displacement position are in good agreement between them. It was confirmed that the periods and amplitudes are also the same; with relative errors of 0 % and 0.5%, respectively.

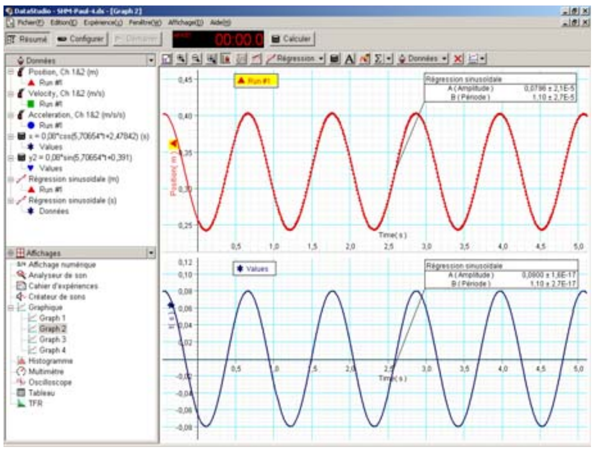

Figure 4. Comparison of calculated and experimental position of mass-spring oscillator.

2.2. Velocity and acceleration of mass-spring in SHM

The two other phenomena which were investigated by students are the velocity and acceleration of mass-spring oscillating in simple harmonic motion. *Science Workshop* software allows the data measurements and graph display of displacement position, velocity and acceleration. First, the position-time data is recorded for some periods of oscillations of vertical mass-spring. Graphs of position, velocity and acceleration as a function of time are displayed in real time in the same window, illustrated in Figure 5. As shown in the top and middle plots the maximum and minimum values of the position occur when the velocity is zero. Likewise the maximum and minimum values of velocity occur when the position is at its equilibrium. It is also observed that both graphs position vs. time and velocity vs. time are periodic waves of the same frequency just shifted by 90° or π/2.

The conclusion drawn from the analysis of the position and acceleration plots (top and bottom) is that when the displacement is zero, acceleration is zero, because the total force applied on the mass is zero; when displacement is maximum, acceleration is maximum, because the total force is maximum. As a result, we conclude that the total force applied by the spring is in opposite direction from the displacement.

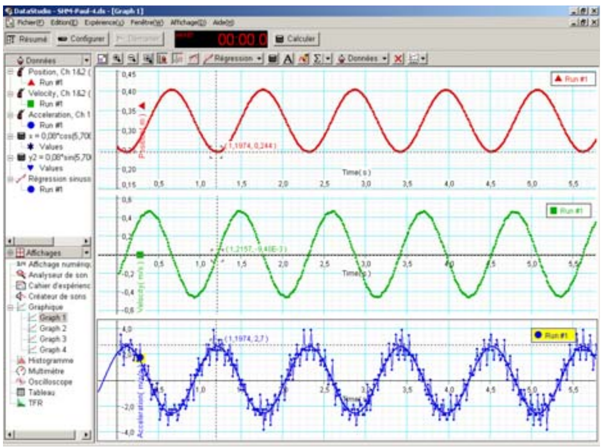

Figure 5. Graphs of position, velocity and acceleration as a function of time of mass spring oscillator.

3. Discussion and conclusion

One effective way of teaching and learning physics is to introduce new pedagogical tools based on the use of CBL experiments in laboratories by providing students with concrete experience of real world phenomena. In our experience students performing experiments using computer-based laboratory have reported improvements in understanding some physical phenomena and their learning appeared equivalent to or better than conventional laboratory instruction [8]. We believe that the implementation of CBL experiments provides students and instructors with several advantages such as data collection and graph display in real time, and interpretation of the data in a reasonably short time frame.

Students manipulating these systems get immediate feedback from the displayed data in graphical form in real-time. The quick display of data allows them to make changes in experimental parameters in a reasonably small time interval. They spend most of their laboratory time observing physical phenomena, interpreting, discussing and analyzing the data [9]. Students performing the CBL experiments scheduled for laboratory courses do not meet any difficulties in handling the variety of probes, interfaces and software. The evaluations by students using CBL experiments are judged positive from the comments written in their lab reports. They appreciate the immediate display of experimental results, the efficient work done by the computer in creating graphs and the use of the function tools available to fit the measured data. The majority confirms a better understanding of the conceptual aspects of the experiments.

Instructors find the use of CBL experiments very attractive and efficient in supervising students for their hands-on experiments. Interaction between groups of students and instructors has led to a greater amount of creative solutions to experimental problems compared to traditional lab. Furthermore, there is a better communication link between instructors and students when discussing theoretical and practical aspect of laboratory experiments.

All our implemented and developed CBL experiments are using *PASCO*-interfaces and sensors and *PASCO Datastudio Science Workshop* software. We believe that similar implemented and developed works can be achieved using software programs, interfaces and sensors which are made by other manufacturers.

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