Using a Wireless Accelerometer with Bluetooth Technology to Estimate the Acceleration of Gravity

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Abstract *The introduction and implementation of physics demonstrations and laboratory experiments based on the use of computer with wireless Bluetooth technology are presented and discussed. 3-axis accelerometer - altimeter is employed to investigate the acceleration due to gravity with three different methods. The three performed experiments are free fall, cart on ramp and simple pendulum.*

Keywords. Wireless, Bluetooth technology, 3-axis accelerometer, Altimeter, Pendulum, Inclined plane, Free fall.

1. Introduction

The 3-axis accelerometer - altimeter of PASCO [1] is an instrument for measuring acceleration of moving object or different variable according to desired results in X, Y and Z axis, calculate the resultant and measures the change in altitude. The device can be used in various experiments and demonstrations in science and technology. In this work, we were interested in the measurements of acceleration due to gravity (g) with three different methods. The experiments are the free fall, the inclined plane and the pendulum. 3-axis acceleration and resultant can be displayed on graphs, allowing students to better understand and interpret data measurements.

This wireless 3-axis accelerometer - altimeter can be employed in indoor and outdoor physics experiments and demonstrations. Several example applications using accelerometers can be suggested to physics students, such as Helmholtz resonator to demonstrate the Helmholtz's equation for a resonating cavity, vibration analysis, and impact force of moving object, etc.

Experiment 1

In the experiment of free fall, the 3-axis accelerometer - altimeter was attached to one end of a nylon string and the other end was fixed to a high stand, and then was released freely from a height of 120 cm. the dropped device was held by a wire to prevent from hitting the floor surface. Furthermore, the surface was covered with a layer of foam to protect the accelerometer from damage in case the string breaks down.

For an object released freely is moving with an initial velocity v_o and a constant acceleration a, obeys the following kinematic equation [2].

$$x = v_o t + \frac{1}{2} a t^2 \qquad (1)$$

x represents the displacement of the object in time t. For an object at rest falling in gravitational field, equation (1) becomes

$$h = \frac{1}{2} g t^2 \qquad (2)$$

Where h is the dropped object. Knowing the height and the time of the free falling body, the acceleration of the gravity can be determined straight forward. In our case, the measurements due to motion were recorded on a wireless interface and the data were analysed through appropriate software on a computer. Accurate acceleration due to gravity is determined on the displayed graph of acceleration as a function of time.

Experiment 2

The second experiment which was performed to determine the acceleration of the gravity was the inclined plane. In this wok, the 3-axis accelerometer – altimeter was attached on frictionless rolling cart on ramp with small angle of inclination, less than 5°, as shown in Figure 1.

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Figure 1. Experimental setup of the 3-axis accelerometer - altimeter mounted on cart on inclined ramp.

The gravitational force is present and pulls directly downwards on the object that is positioned on the ramp. The force acting on the object parallel to surface of inclined plane in frictionless movement is given by [3-4].

$$Mg\sin\theta\,, \tag{3}$$

and the expected value of the acceleration is

$$a = g\sin\theta \Rightarrow g = \frac{a}{\sin\theta} \tag{4}$$

Where Θ is the angle of inclination, *a* represents the acceleration and *g* is the acceleration of the gravity. The cart was rolled from the top to the bottom of a ramp with an inclined angle of 3°. The X-axis of the accelerometer- altimeter was parallel to the inclined plane. The acceleration on X-axis with the resultant as a function of time were recorded and displayed graphically on a computer using *Datastudio* software analysis of PASCO.
The acceleration due to gravity is calculated from the acceleration of the rolling cart and the inclined angle.

Experiment 3

The experiment is related to the movement of a simple harmonic motion (SHM) of a pendulum, where a 3-axis accelerometer - altimeter was attached to unstretchable thin nylon string and the pivot such that the accelerometer hung few centimeters above the floor, as shown in Figure 2. A hook collar attached to a high bar support worked as the pivot point. The X-axis of the measurement device was pointed in line with the pendulum arm and the Y-axis is directed towards the amplitude motion. The length between the center of the weight and the pivot point was 175 cm. The pendulum was allowed to swing for several oscillations, with small amplitudes, less than 15°, before stopped. The oscillation period of a pendulum is given by the following equation [5-6].

$$T = 2\pi\sqrt{\frac{l}{g}} \Rightarrow \qquad g = \frac{l}{\left(\frac{T}{2\pi}\right)^2} \tag{5}$$

Figure 2. Experimental setup of the 3-axis accelerometer - altimeter as a simple pendulum.

Where *l* is the length of the pendulum between the pivot and the center of gravity, *g* is the gravitational acceleration, and T is the period of one complete swing. The data of oscillation period of Y-axis segment was recorded and analysed by *Datastudio* software application. The Fast Fourier Transform (FFT) was applied to convert the time domain data to frequency domain. The result is plot showing the relative amplitude as a function of frequency, the dominant frequency is used to calculate the period of oscillation (T).

2. Results and discussion

The acceleration due to gravity is determined, by means of three different methods, using a 3-axis accelerometer - altimeter with a Bluetooth wireless technology. Data measurements of free fall, inclined plane and pendulum experiments are plotted in Figures 4, 5 and 6, respectively.
The mean value of acceleration due to gravity, due to free fall, obtained from five trials was 9.75±0.08 ms^{-2}. The measurement of g is obtained directly from the plot of acceleration in X-axis orientation as a function of time, as reported in Figure 3. The experimental result is in good agreement with theoretical value with an error of 0.6 %. The

reproducibility of the acceleration of the gravity was dependent on the precision the height drop.

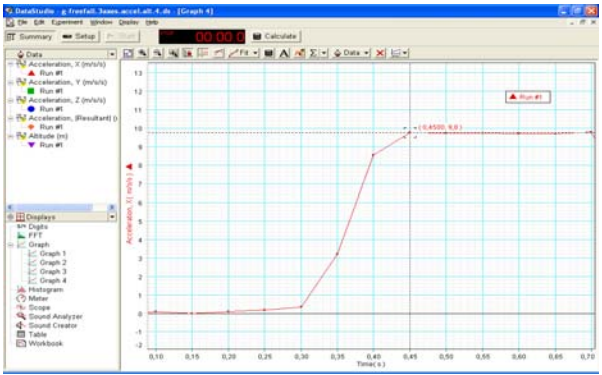

Figure 3. Typical graph of free fall 3-axis accelerometer - altimeter. X-axis direction acceleration as a function of time.

The result of the acceleration in Y-axis direction, parallel to the ramp, was obtained from the plot of acceleration versus time, as shown in Figure 4. The average value of acceleration of five trials was 0.5±0.02 ms^{-2}. The gravitational acceleration was calculated using Eq. (4); with an inclined angle of 3°, the mean experimental value of g was 9.61±0.04 ms^{-2}. The error between the theoretical and experimental value was 2 %.

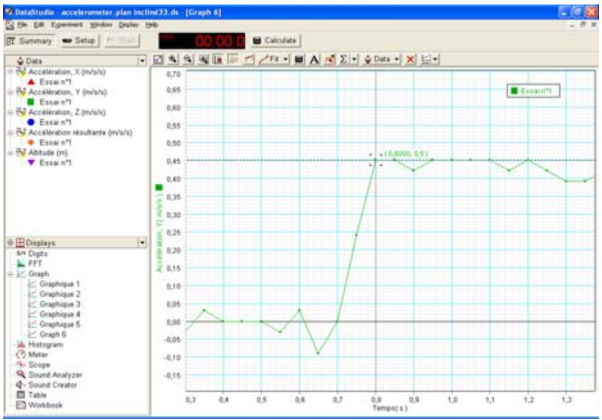

Figure 4. Typical graph of rolling cart on ramp with inclined angle of 3°. The Y-axis accelerometer - altimeter oriented downwards the inclined plane.

Data measurements of periods of accelerometer-altimeter which was used as a simple pendulum were plotted as a function of time. The calculated gravitational acceleration was obtained using The Fast Fourier Transform (FFT), where the time data domain was converted to frequency domain. The Fast Fourier Transform in the *Datastudio* software application was used to plot the relative amplitude versus frequency. A typical graph of FFT is reported in Figure 5.

As can be seen from this plot, the dominant frequency was 0.77 Hz. There are two acceleration peaks per cycle since the pendulum swings past centre twice. Therefore, the frequency of the pendulum is half that of the FFT result, or 0.385 Hz. Since, the period T = 1/frequency. The resulting pendulum period was 2.597 seconds. Using Eq. (5), the mean calculated gravitational acceleration of five trials was 10.23±0.06 ms^{-2}. The error between the theoretical and experimental value of g was 4.2 %.

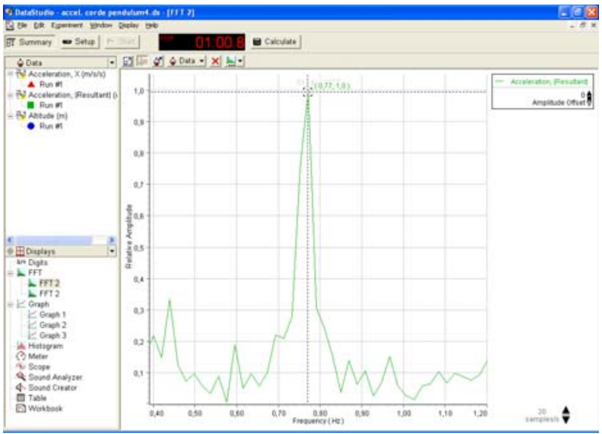

Figure 5. Fast Fourier Transform plot - representing relative amplitude of the pendulum as a function of frequency.

3. Conclusion

We have reported the results of gravitational acceleration of three different methods using a wireless Bluetooth technology with computer. The obtained results are within the accepted theoretical value of g. The experimental value of g of the free fall is more accurate than the inclined plane and the pendulum with 9.75, 9.61 and 10.23 ms^{-2}, respectively. The findings of this work could help science students and teachers to carry out experiments and demonstrations using such advanced wireless technology. Experiments using wireless Bluetooth technology with computer could be performed inside or outside the laboratory.

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