Smartphone acceleration sensors in undergraduate Physics experiments

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Abstract

In this work, the uses of the smartphones' acceleration sensors in Physics teaching experiments are discussed. This is performed by means of a series of examples within the topic of Mechanics developed at the Higher Technical School of Design Engineering (ETSID in Spanish) of the Universitat Politècnica of València (Spain). The uniformly accelerated linear motion is illustrated by the free fall of a body in the Earth gravity. Subsequently, smartphones undergoing mechanical oscillations are described. In all cases, a quantitative study using the kinematic equations has been performed. All these examples show that the acceleration sensor of the smartphones, which is very familiar to students, finds amenable applications in introductory and first-year university Physics courses.

Keywords: *Smartphones, Sensors, Physics lab experiments.*

1. Introduction

Portable devices find an increasing use in all the teaching levels of Physics over the past years. This is the case of digital cameras [1], webcams [2], optical mouse of computers [3] [4], wiimote [5], other game console controllers [6], among others.

Digital techniques have been widely used to visualize Physics concepts. [7] [8] By analyzing the recorded video, distances and time intervals can me measured in order to fully determine the trajectory of the moving body. On the other hand, wireless devices (such as the wiimote) have also been applied in Physics teaching [9,10]. The wiimote devices have a three axis accelerometer which communicates with the game console using a bluetooth device. The wiimote gives Physics teachers a low cost way to track the motion in a variety of Physics experiments [11]; however, it is not a common device at the Physics laboratories.

More recently, smartphones have been incorporated into the variety of portable devices in Physics teaching. Smartphones integrate in one device many capabilities which were apart previously. These capabilities may include a camera, a microphone, a speaker, an accelerometer sensor, a magnetic field sensor, and an ambient light sensor.

In this contribution, we focus on the accelerometer sensor of the smartphones and its applications to the study of phenomena within the topic of Mechanics where the quantity "acceleration" plays a central role. This is a very basic topic in all General Physics courses for Engineering and Physics degrees. We go through a series of examples while we comment on various works published recently in the literature which include our own contributions.

The outline of this work is the following. First we briefly introduce the acceleration sensor and two Android applications to handle it, basically those we have used in our experiments. The first example of application presented is the uniformly accelerated motion of a free falling body in Earth gravity. Subsequently, two examples of free and damped oscillations are explained. Finally, some conclusions and outlook are commented.

2. Acceleration sensor and computer application

Nowadays, most of smartphones carry an acceleration sensor. In simple words, the accelerometer sensor is a micro-electro-mechanical system. It is based on three mutually perpendicular silicon circuits, each one oscillating in one direction as a ball hanging on a spring whose movement is restricted to one direction. The shift in the position of the moving body is usually measured by a capacitive effect. The measurement of the acceleration sensors can be registered with a smartphone application.

```
# Accelerometer Values
# filename:  default__1.txt
# Saving start time: Fri Oct 25 19:12:46 GMT+02:00 2013

# sensor resolution: 0.01197m/s^2
#Sensorvendor: The AMI306 Android Open Source Project, name:
AMI306 3-axis Acceleration sensor, type: 1,version : 1, range
19.6

# X value, Y value, Z value, time diff in ms
  -0.032   -0.018   -0.051      22
   0.05     0.009   -0.037      22
   0.08     0.035   -0.042      21
   0.028    0.031   -0.064      21
  -0.053    0.019   -0.084      21
  -0.057    0.008   -0.093      21
   0.001    0.016   -0.075      22
   0.045   -0.002   -0.041      21
   0.005    0.015   -0.028      21
  -0.047    0.013   -0.043      22
  -0.052   -0.005   -0.039      21

   ...       ...      ...       ...
```

Figure 1. Output file of the Accelerometer monitor application.

Here a briefly present the free Android application *"Accelerometer Monitor ver 1.5.0"* we have used in our experiments. This application takes 348 kB of SD card memory and can also be downloaded from Google play website [12]. This App shows the acceleration components a_x, a_y and a_z on x, y and z- axes at each time step. The resolution of the sensor in the measurement of the acceleration is $\delta a = 0.01197$ m/s^2 and the average sampling time is δ_t=0.02 s. This application also allows saving an output file, from which the data can be retrieved for further analysis. The output of the mobile application with the acceleration data is collected in an ASCII file (Figure 1).

First, a heading with some information such as "saving start date and time", "sensor resolution" and "sensor vendor", can be found. Following the heading, the sensor measurements are shown. The first three columns indicate the acceleration in the three perpendicular axis, x (perpendicular to the device, positive to the right), y (along the device, positive upward) and z (perpendicular to x and y-axis, with positive direction as coming out perpendicularly from the device display).

Once the applications have been downloaded to the mobile device, a small test can be performed to proof their correct working. When the mobile is left quiet on a horizontal surface, the output curves for the acceleration must exhibit values very close to zero for x and y-axes, and around 9.8 m/s^2 for the z-axis.

3. Uniformly accelerated linear motion (free fall)

Probably, the simplest experiment we can perform with the mobile acceleration sensor is the study of a body which falls in the gravitational field of the Earth. This experiment was treated in reference. [13] Authors suspended a smartphone from a string. After cutting the string, the smartphone fell freely for a period of time until getting to a soft surface which stops its motion. With the measurement of the fall time and the initial height, the value of the acceleration of Earth gravity was obtained.

In this work, we repeated the experiment for six different values of the initial height. The falling body follows a uniformly accelerated linear motion, for which, the position as a function of time is

$$H(t) = H_0 + v_0 t - g t^2/2 \,, \quad (1)$$

where H_0 is the initial height, v_0 the initial velocity, and g the acceleration of gravity. For H and v_0 equal zero in equation (1) we obtain,

$$H_0 = (g/2)t^2 \ . \qquad (2)$$

By using the acceleration sensor of a smartphone Samsung Galaxy S2 bearing an Android version 2.1 and with mass, (0.1350 ± 0.0001) kg, the time in equation (2) is measured as a function of the initial height, H_0. The free fall time, t is represented by the time length of the plateau of the curve in Figure 2. The experimental points were fitted to the equation (2) by a Least-squares method in Figure 3. The resulting value for the acceleration of gravity was $g = (10.92 \pm 0.13)\ m/s^2$. In this experiment, the air drag force has not been considered.

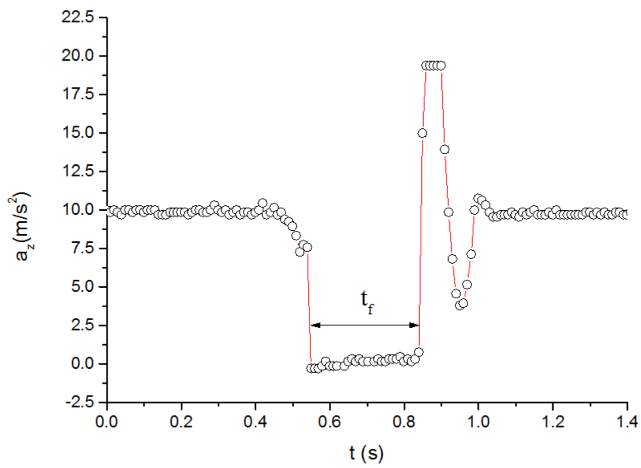

Figure 2. Acceleration sensor measurements for the free fall time of the smartphone.

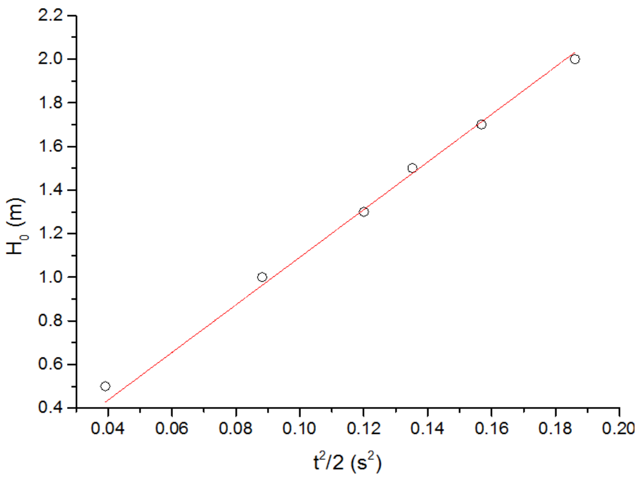

Figure 3. Experimental data for the free fall time of the smartphone.

4. Free harmonic oscillations

The smartphone acceleration sensor is also very suitable for the study of mechanical oscillations. [14] In this contribution we present the main aspects of the experiments designed to study free and damped oscillations.

In Figure 4, a photograph of the experimental setup is shown. In this figure the following elements are present: (1) the smartphone, (2) cart, (3) air track, (4) spring, (5) photometer and (6) fixed end. The smartphone used in the experiments was an LG-E510 bearing an Android version 2.3.4. The mass of the phone and the cart were 124.0 g and 180.6 g, respectively. The data was collected with the Accelerometer Monitor application version 1.5.0 whose features were commented above. The force constant of the spring was $(189 \pm 7)\ \mathrm{N}/m$.

To initiate the free oscillation experiment the air supply of the air track is switched on. This allows a layer of air between the cart and the air track to decrease the friction. Under these conditions the motion of the cart is started with almost no friction. The acceleration *versus* time can be represented in terms of a sinusoidal function,

$$a(t) = A sin(\omega_0 t + \varphi_0)\ , \qquad (3)$$

where A is the acceleration amplitude, ω_0 is the angular frequency, and φ_0 is the phase constant. By the way, the smartphone in figure 4 is moving with harmonic oscillations. The sinusoidal signal can be seen on the display. In figure 5, the experimental data of the acceleration are shown along with a fit to above equation using the Levemberg-Marquardt algorithm [15]. The parameters resulting from the fit are shown in Table 1. The value of the period calculated from the fitted frequency and from the direct measurement of the time with photometer were compared yielding a very good agreement. The discrepancy was less than 1 %.

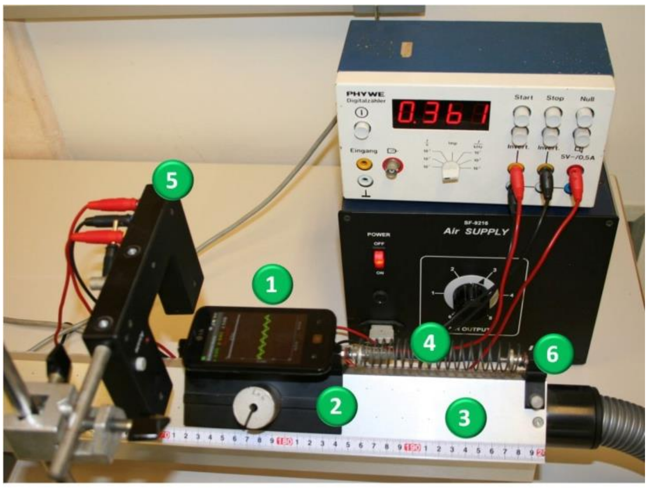

Figure 4. Photograph of the experimental setup with the smartphone moving with free oscillations.

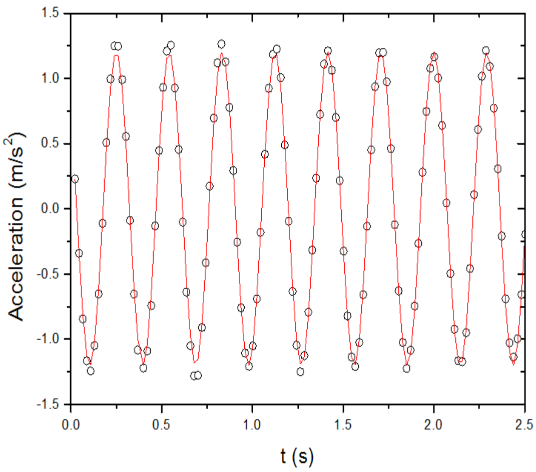

Figure 5. Experimental acceleration data (open circles) and fitted curve (solid line) for the free harmonic oscillation.

Table 1. Fit of the experimental acceleration data to equation 3.

$A \pm \delta A\ (m/s^2)$	$\omega_0 \pm \delta\omega_0\ (rad/s)$	$\varphi_0 \pm \delta\varphi_0\ (rad)$	R^2
1.204 ± 0.006	21.546 ± 0.005	2.479 ± 0.009	0.9968

5. Damped harmonic oscillations

In order to study damped harmonic oscillations, the air supply was decreased in the air track (see Figure 4). This causes some friction to appear between the glider and the air track. The damping of the oscillations of the acceleration can be described by the following equation of the harmonic damped oscillation,

$$a(t) = De^{-\gamma t} sin(\omega t + \varphi) \ , \quad (4)$$

where D is the initial amplitude of the acceleration, γ is the linear damping constant, ω is the angular frequency, and φ is the phase constant. This damped oscillation can be also observed on the display of the smartphone in figure 6. In figure 7, the experimental data of the acceleration are plotted along with a fit to the equation (4). The parameters resulting from the fit are registered in Table 2. The relaxation time was calculated as,

$$\tau = \frac{T_d T_{fit}}{2\pi\sqrt{T_d^2 - T_{fit}^2}} \ , \quad (5)$$

where T_d is the period of the damped oscillations and T_{fit}, the period of the free oscillations. This result was compared to $\tau = 1/\gamma$, where γ is the fitted value registered in Table 2. A percentage discrepancy of 0.59 % was obtained, indicating the good agreement between both calculations.

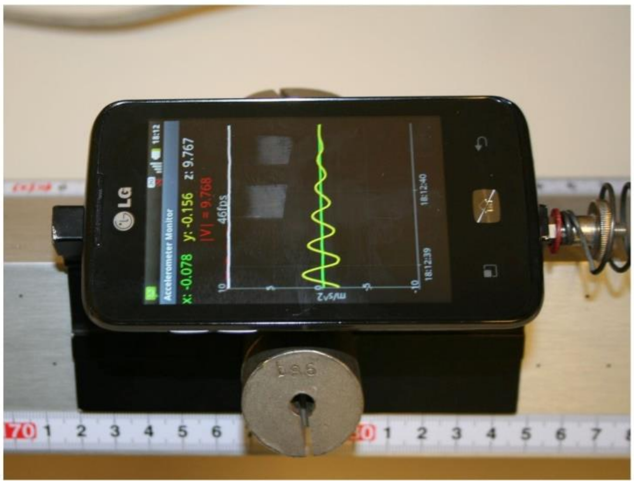

Figure 6. A close-up of the smartphone moving with damped oscillations.

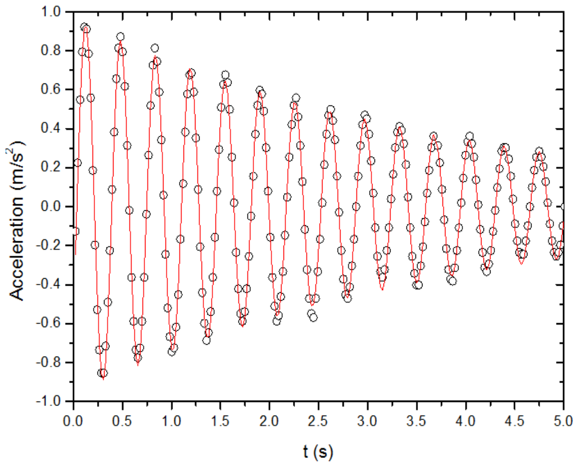

Figure 7. Experimental acceleration data (open circles) and fitted curve (solid line) for the damped harmonic motion.

Table 2. Fit of the experimental acceleration data to equation 4.

$D \pm \delta D\ (m/s^2)$	$\gamma \pm \delta\gamma\ (s^{-1})$	$\omega \pm \delta\omega\ (rad/s)$	$\varphi \pm \delta\varphi\ (rad)$	R^2
0.967 ± 0.009	0.258 ± 0.004	17.671 ± 0.001	-0.629 ± 0.005	9927

6. Conclusions

There is a number of works on the smartphone acceleration sensor which demonstrate the feasibility of using this sensor in Physics teaching experiments, mostly in the topic of Mechanics which is present in all Introductory and General Physics Courses. In this work we have shown examples for several types of one-dimensional motions where the acceleration plays an important role in characterizing the systems. They include the uniformly accelerated and oscillatory motions and have been developed at the Higher Technical School of Design Engineering (ETSID in Spanish) of the Universitat Politècnica of València (Spain). Other sensors such as the light ambient sensor and the magnetic field sensor can be also integrated to Physics teaching experiments.

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