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Oscillations studied with the smartphone ambient light sensor

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Abstract

This paper makes use of a smartphone's ambient light sensor to analyse a system of two coupled springs undergoing either simple or damped oscillatory motion. The period, frequency and stiffness of the spring, together with the damping constant and extinction time, are extracted from light intensity curves obtained using a free Android application. The results demonstrate the instructional value of mobile phone sensors as a tool in the physics laboratory.

(Some figures may appear in colour only in the online journal)

1. Introduction

Sensors found in common electronic devices can be used as a useful tool to bring students closer to measuring techniques in the physics laboratory. Digital cameras [1], webcams [2], optical computer mice [3, 4], Wii classic controllers [5], Xbox Kinect sensors [6] and other video game console controllers [7] have been used to carry out new laboratory experiments that allow basic concepts in physics to be visualized. The Wiimote allows several objects to be tracked simultaneously by means of a Bluetooth connection and exploits the three accelerometers to follow them in 3D; these properties can be applied to many physics experiments [8]. The use of the Xbox Kinect sensor allows measurement of 3D positional data with a time base. However, these devices require specific software and are not widely available in the physics laboratory. On the other hand, the widespread use of mobile phones among young people and

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the constant evolution of the technology on these devices make them an attractive tool for possible application in scientific demonstrations and experimental measurements.

Recently, Castro-Palacio *et al* [9, 10] exploited the use of the smartphone digital gyroscope to study a system of coupled oscillators. In this paper we present a similar study, but one that uses the ambient light sensor of the smartphone. Light sensors are common devices in optical teaching physics laboratories [11], but students can use their own phones to carry out the measurements, thus increasing their interest and motivation when performing the experiment. Here, we detail the experimental set-up and the mathematical model used to analyse the variation of the recorded light intensity. The data acquired are used to determine important parameters describing the simple harmonic and damped oscillatory motion. The study of harmonic and damped oscillations is included in most introductory physics syllabi, like those generally covered in the first courses of university degrees [12].

2. Basic theory

The oscillatory movement along the x axis of an object with mass m coupled to two springs with stiffness k and shifted with respect to the equilibrium position is described by the simple harmonic movement equations:

$$x(t) = A \sin(\omega_0 t + \varphi) \quad (1)$$

$$T = \frac{2\pi}{\omega_0}, \quad (2)$$

where A is the shift amplitude, φ is the initial phase and ω_0 is the angular frequency, which is related to the oscillation period T by equation (2). Once the frequency of the simple harmonic movement is known, the spring constant k can be calculated using the following expression:

$$k = \frac{m\omega_0^2}{2}. \quad (3)$$

It is also well known that the light intensity is inversely proportional to the square of the distance between the detector and the light source, assuming that one has a point light source whose power is spread in a spherical wave front. Therefore, if one places a light source in the same axis of the linear movement of the oscillatory system the intensity recorded by the light sensor is described by the equation:

$$I(t) = I_0 \frac{d_0^2}{(d_0 + A \sin(\omega_0 t + \varphi))^2}, \quad (4)$$

where I_0 is the light intensity in the equilibrium position and d_0 is the distance between detector and the light sensor when the system is at the equilibrium position.

When the object of mass m coupled to the springs is subjected to some kind of dissipative force, the oscillatory movement of the system is a damped oscillation described by the following equations:

$$x(t) = B e^{-\gamma t} \sin(\omega t + \varphi) \quad (5)$$

$$\omega = \sqrt{\omega_0^2 - \gamma^2}, \quad (6)$$

where B is the oscillation amplitude, γ is the damping constant, ω_0 is the simple harmonic frequency and ω is the damped oscillation frequency. In this case the light intensity measured by the light sensor in the same configuration as in the previous section will be given by

$$I(t) = I_0 \frac{d_0^2}{(d_0 + B e^{-\gamma t} \sin(\omega t + \varphi))^2}. \quad (7)$$

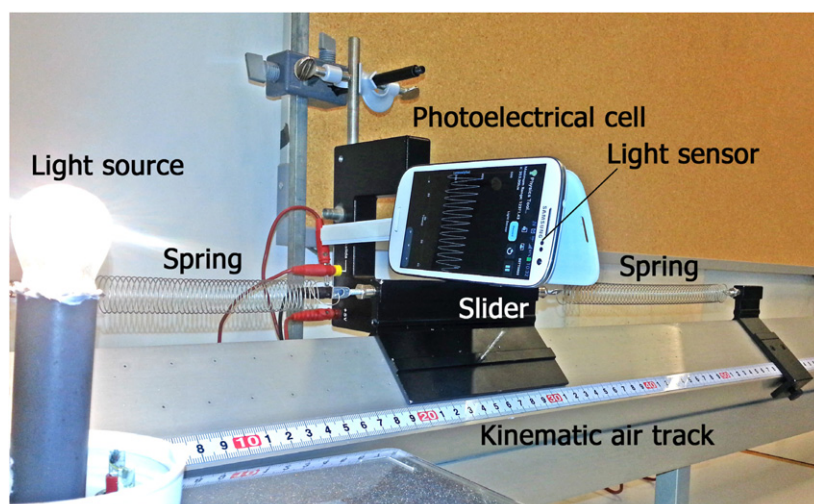


Figure 1. Picture of the coupled springs system set-up.

Therefore, similarly to the case of the previous subsection, we can obtain information about the oscillatory movement from the variation of the light intensity with the detector–source distance from equation (7).

3. Experimental set-up

The experimental set-up is shown in figure 1. A slider is placed on an air track and connected to fixed ends of the track using two springs with the same stiffness. A smartphone is attached to the slider with the ambient light sensor facing the light source along the direction of the slider’s motion. The smartphone used to carry out the experiment is a Samsung Galaxy SIII, running version 4.0.4 of the Android operating system.

The variation of the light intensity measured by the smartphone as a function of time was recorded using the freely available Physics Toolbox Light Sensor app⁵ and the acquired data analysed with statistics software. The smartphone sensor was calibrated with a photometer. Using this experimental set-up we carried out two experiments to study simple harmonic and damped oscillatory motion. Both types of motion can be studied just by changing the slider’s mass (adding or removing weight) and/or the air flux of the kinematic air track [13]. In this way it is possible to find the optimal conditions to study both types of movement.

4. Results

4.1. Simple harmonic motion

Using relatively low weights for the slider and/or relatively high air fluxes in the kinematic air track, we can obtain conditions closer to friction-free movement so that the oscillating system describes a simple harmonic motion. Figure 2 shows the results of the recorded oscillations with the light sensor as a function of time for different system masses (slider with weights + smartphone).

⁵ Veyra software, <https://play.google.com/store/apps>.

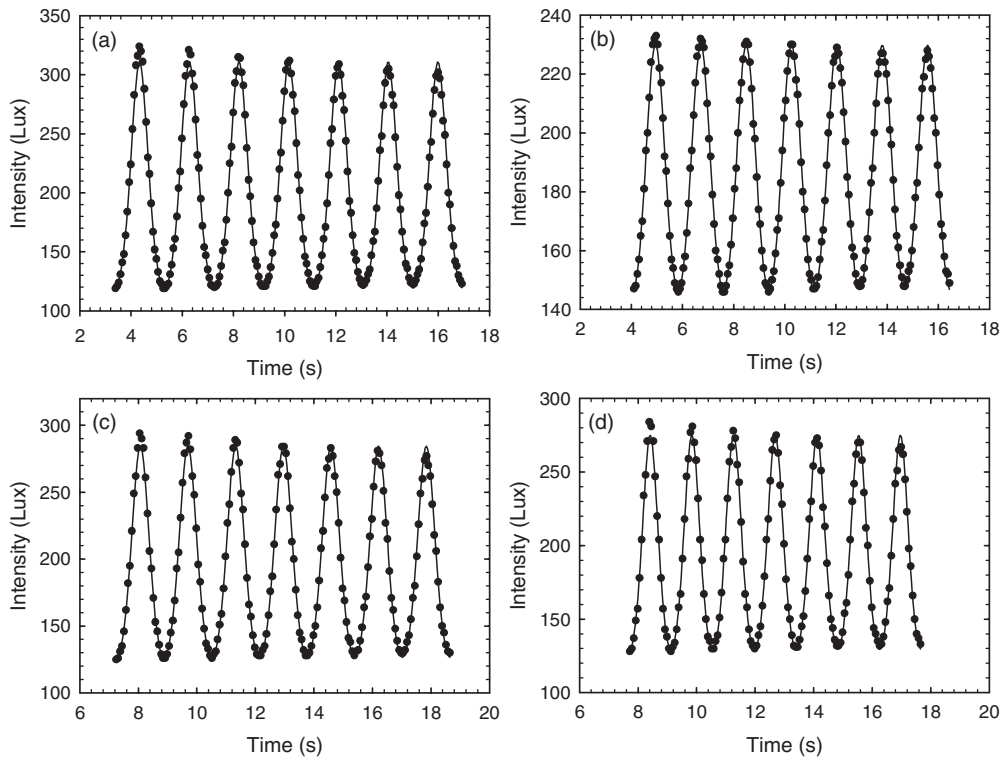


Figure 2. Light intensity versus time in a system with two coupled springs and with a mass of (a) 646, (b) 506, (c) 450 and (d) 310 g.

Table 1. Frequency, period and stiffness of the springs obtained with the smartphone (data fitted to equation (4)) and using other methods (Phywe and static).

Mass (kg)	ω_0 phone (s^{-1})	T phone (s)	ω_0 Phywe (s^{-1})	T Phywe (s)	k phone (N/m)	k static method (N/m)
0.646(1)	3.2348(1)	1.9424(1)	3.242(1)	1.938(2)	3.380(7)	3.6(2)
0.506(1)	3.5442(1)	1.7728(1)	3.627(4)	1.732(2)	3.178(8)	
0.450(1)	3.8584(1)	1.6284(1)	3.897(5)	1.612(2)	3.350(9)	
0.310(1)	4.4092(1)	1.4250(1)	4.39(3)	1.431(2)	3.013(10)	

The experimental data displayed in figure 2 show a weak damping that can be neglected as a first approximation. These data were fitted to equation (4) and a regression coefficient R^2 higher than 0.995 was obtained in all cases, indicating the high quality of the data. The oscillation frequencies (periods) obtained by these fits (table 1) decrease (increase) with the mass of the system. These period and frequency values are compared with those obtained from a photoelectric cell synchronized to a chronometer (Phywe). The good agreement between the values obtained using both methods (in most cases below 1% divergence) supports the validity of the results obtained with the smartphone.

The stiffness of the springs can be obtained using the so-called dynamical method, which is based on measurement of the time needed for the slider to carry out a determined number of oscillations. Equation (3) allows us to determine the stiffness of the springs, assuming that in

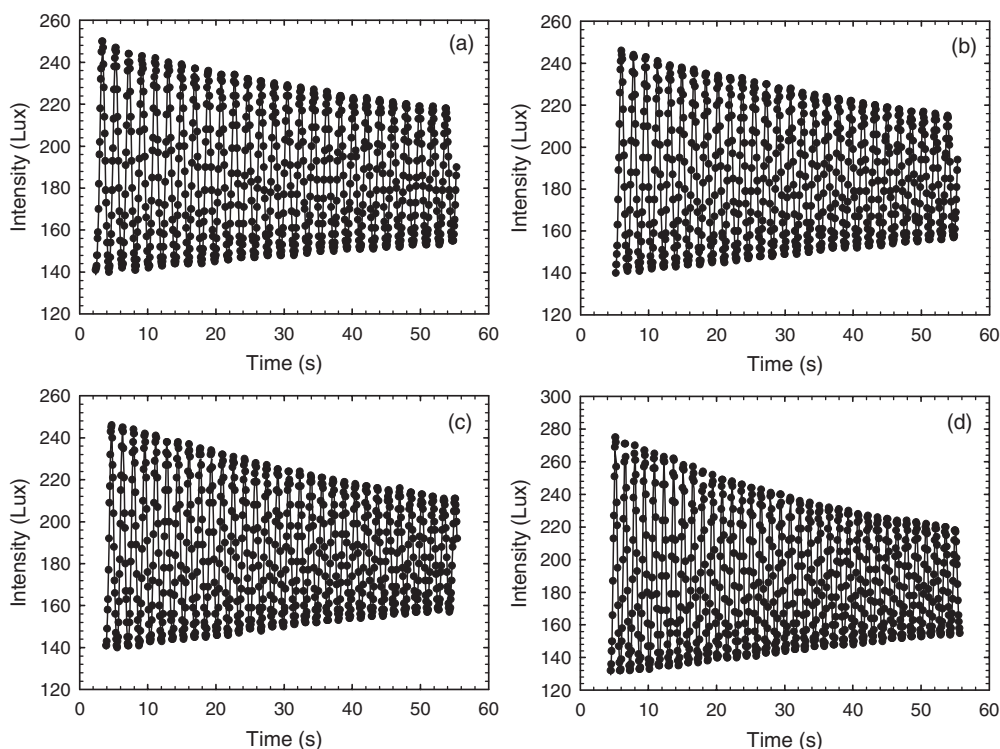


Figure 3. Light intensity versus time in a system with two coupled springs, with the action of the dissipative force and masses of (a) 646, (b) 506, (c) 450 and (d) 310 g.

our case both springs are identical. The values obtained for k are compared (table 1) with the average value of the stiffness obtained by the static method in both springs separately. In the static method the spring is held vertically and the elongation produced by different weights suspended from it is related to the stiffness by

$$L = \frac{g}{k}m + L_0. \quad (8)$$

4.2. Damped oscillatory movement

The increase of the mass of the slider and/or the reduction of the air flux in the kinematic track causes an increase in the action of the dissipative force between the slider and the track, giving rise to a damped oscillatory movement. Figure 3 shows the results of the recorded oscillation as a function of time for different system masses using the light sensor (slider with weights + smartphone).

The experimental data shown in figure 3 were fitted using equation (7). The quality of the fit can be seen in the values of the regression coefficient R^2 , always higher than 0.98. Again, the high value of the R^2 coefficient indicates the high quality of our experimental data. Table 2 shows the oscillation frequencies and the damping coefficients obtained by the fits for the different system masses with a constant air flux. It is noteworthy that the damping coefficient

Table 2. Frequency, damping time and stiffness of the springs, and extinction time obtained with the smartphone (data fitted to equation (7)) and using other methods (static).

Mass (kg)	Ω phone (s ⁻¹)	γ phone (s ⁻¹)	ω_0 phone (s ⁻¹)	τ phone (s)	k phone (N/m)	k static (N/m)
0.646(1)	3.2433(1)	0.010(2)	3.2(6)	50(10)	3(1)	3.6(2)
0.506(1)	3.5485(1)	0.012(2)	3.5(6)	41(7)	3(1)	
0.450(1)	3.8681(1)	0.013(2)	3.9(6)	38(6)	3(1)	
0.310(1)	4.4108(1)	0.015(2)	4.4(6)	33(4)	3(1)	

decreases with the increase of the system mass. Once the damping coefficient is known, it is possible to obtain the value of the oscillation extinction time using

$$\tau = \frac{1}{2\gamma}. \quad (9)$$

Finally, from equation (6) the value of the oscillation frequency corresponding to friction-free motion (ω_0) was obtained. This was, in turn, used to derive a value for the spring constant k , again assuming springs of identical stiffness (see table 2). The uncertainties in the determination of the spring constant from the damped oscillatory motion data are considerably larger than those associated with the analysis of simple harmonic motion.

5. Conclusions

We have successfully studied the harmonic and damped oscillations of a system with two coupled springs using the smartphone ambient light sensor and the Physics Toolbox Light Sensor Android app to record the light intensity as a function of time.

We have obtained the frequency, period and stiffness of the spring, and the damping constant and the extinction time of the simple harmonic and damped oscillatory movements. The results obtained for the frequency, period and stiffness of the spring are in good agreement with those obtained using more traditional methods, and demonstrate the value of the smartphone ambient light sensor as a tool in the undergraduate physics laboratory.

Acknowledgments

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