IJESRT
INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

USE ROTATIONAL SENSORS AND ACCELERATION IN SMARTPHONE FOR PHASE SPACES

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ABSTRACT

In Todays World The compound system, wheel plus smartphone, defines a physical pendulum which can rotate, giving full turns in one direction, or oscillate about the equilibrium position (performing either small or large oscillations). Paradigm shifts tend to appear in response to critical anomalies or an accumulation of them as well as the proposal of a new theory with the power to encompass both older relevant data and explain relevant anomalies. New paradigms tend to be most dramatic in sciences that appear to be stable and mature, as in physics at the end of the 19th century. A paradigmatic physical system as the physical pendulum is experimentally studied using the acceleration and rotation (gyroscope) sensors available on smartphones and other devices such as iPads and tablets. A smartphone is fixed to the outside of a bicycle wheel whose axis is kept horizontal and fixed. Measurements of the radial and tangential acceleration and the angular velocity obtained with smartphone sensors allow a deep insight into the dynamics of the system to be gained. In addition, thanks to the simultaneous use of the acceleration and rotation sensors, trajectories in the *phase space* are directly obtained. The coherence of the measures obtained with the different sensors and by traditional methods is remarkable. Indeed, due to their low cost and increasing availability, smartphone sensors are valuable tools that can be used in most undergraduate laboratories.

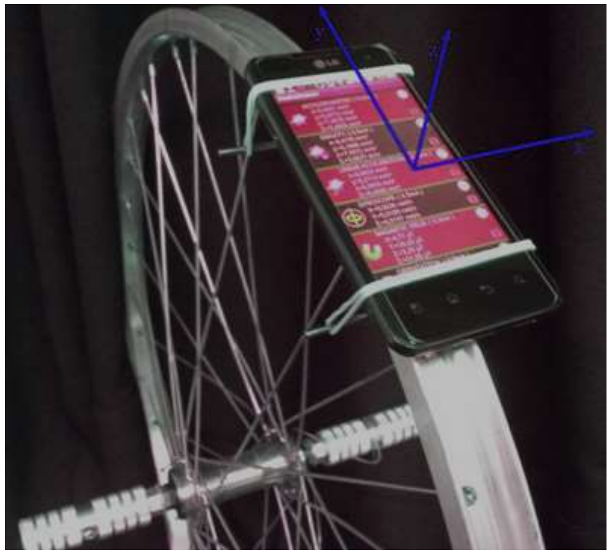
KEYWORDS: smartphone, rotation sensor, gyroscope, acceleration sensor.

INTRODUCTION

The focus of this work is the study of a paradigmatic system in classical mechanics, a physical pendulum, using smartphone acceleration and rotation sensors simultaneously. A physical pendulum is a rigid body, which can rotate around a fixed point, or *pivot*, located at non-zero distance from the centre of mass. In our experiment, a physical pendulum was built using a bike wheel and a smartphone as described in the next section. According to press releases, in 2013 more than one billion smartphones were sold worldwide. These devices usually incorporate several sensors, including accelerometers, gyroscopes, and magnetometers.

Although these devices are not supplied with educational purposes in. Nowadays, there is intense debate and research on the teaching and learning of Physics. Several authors have highlighted the importance of involving students in their own learning process (see [2] for a resource letter). A recent approach, known as *active-learning instruction*, insists on the involvement of the students in their own learning more deeply and more intensely than in traditional instruction schemes. One feature is the incorporation of classroom and laboratory activities that encourage students to express their thinking through several actions that go beyond the traditional, more *passive*, procedures. A possible alternative is the analysis and discussion of everyday problems [3], or the proposal of simple demonstrative experiences using non-sophisticated equipment . Another option is non-classroom activities, such as those in amusement parks, either mechanical or water based . Indeed, as recent studies have pointed out , the rewiring approach to learning suggests that the knowledge that students bring to a classroom should be viewed as a productive resource upon which to build, rather than as an impediment. In the experience proposed here, the use of an ubiquitous and everyday device such as a smartphone is intended as a way to transform science into an activity firmly linked to the real world.

Figure:1



SETUP OF EXPERIMENT

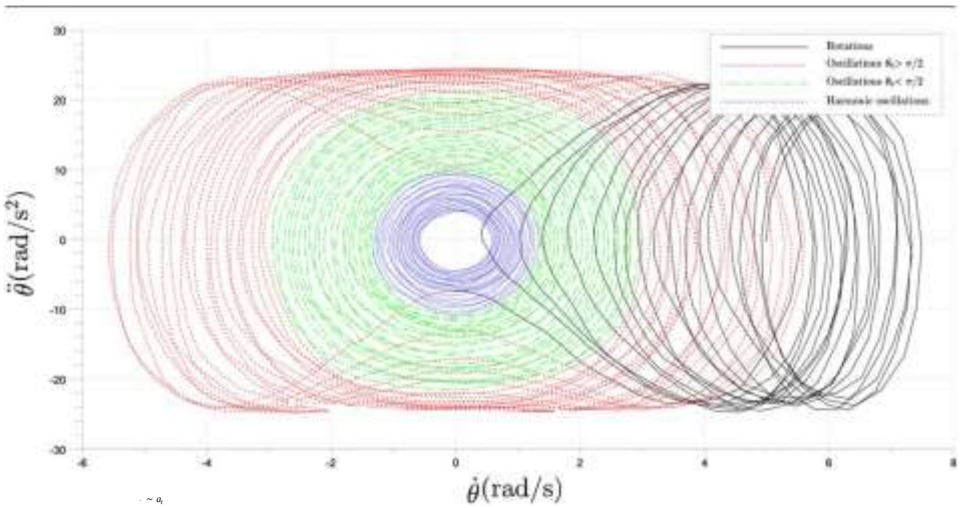
The distance between the centre of mass of the wheel and the centre of mass of the smartphone is R = 0.300 m and the mass of the smartphone is m = 0.146 kg. The experimental setup consists of a smartphone mounted in the periphery of a bicycle wheel that can rotate freely in a vertical plane, as shown in figure. The smartphone is an LG Optimus P990 2X (three-axis accelerometer KXTF9 Kionix, accuracy 0.001 m s^{-2}, three-axis gyroscope MPU3050 Invensense, accuracy 0.0001 rad s^{-1}) was used. The application AndroSensor [7] running under the Android operating system was employed to record the values measured by the sensors. Usually, the different sensors register vector magnitudes along three axes oriented, as indicated in figure 1. In the present experiment, the relevant magnitudes are the component of the angular velocity reported by the rotation sensor according to the *x*-axis and two components of the acceleration according to the *y*- and *z*-axis, corresponding to the tangential and radial accelerations respectively. Once registered, data can be exported and analysed using appropriate software.

The moment of inertia of the physical pendulum is determined as follows. First, the period of the small oscillations of the wheel (without the smartphone) suspended from a fixed point located at the inner part of the rim is obtained. Using the parallel axis theorem, the moment of the inertia of the wheel with respect to the geometrical centre is found to be I_W = 0.039 kg m^2. Next, thanks to the additivity, the moment of inertia of the compound system, wheel and smartphone, is easily calculated as $I = I_W + mR^2$ = 0.052 kg m^2.

RESULTS AND DISCUSSION

We start analysing the dynamics of the system by plotting in figure 2 both the radial acceleration a_r and the angular velocity ω as a function of time. At the beginning, the wheel is rotating in one direction; however, at t = 30 s, (indicated by the green circle), due to the effect of the weak dissipation, the angular velocity vanishes for the first time, the wheel reverses the direction of spinning and starts to oscillate around the stable equilibrium point. During the rotational motion, the displayed maxima and minimums of both magnitudes correspond to the smartphone at the lowest or the highest point of the trajectory, respectively Diagram shows the patterns of oscillations occurred during the experiment.

Figure:2



At the first stage of the experiment, the wheel is rotating performing full revolutions in the same direction (black lines). As the energy is dissipated, when the angular velocity changes its sign for the first time, the wheel starts oscillating about the stable equilibrium position. According to the amplitude of the oscillations, the curve is plotted in different colours: large amplitudes (red), intermediate amplitudes (green) and, at the end of the realization, the trajectory can be approximated by ellipses, given by equation (4), indicating harmonic oscillations (blue lines).

CONCLUSION

The use of smartphones in general presents a clear advantage in comparison with the use of other methods, such as interfaces or video analysis, which require costly devices and/or special training. We remark that the use of the smartphone sensors allows a broad spectrum of measures applicable in different mechanical experiments. The potential is more significant if we consider the simultaneous use of acceleration and rotation sensors that allows, among other things, us to access the phase space and get a physical representation of a rather abstract concept. This methodology can be extended to other experiments in classical mechanics, such as a simple pendulum, a torsion pendulum, a spring pendulum, and coupled or forced oscillators. The use of devices that are becoming increasingly available for secondary or university students, such as smartphones, helps to reduce the gap between science and everyday experience.

The learning of science, usually restricted to classrooms and laboratories, materializes in this way into the hands of all students, allowing them to carry out specific activities beyond traditional ones, such as measurements of multiple variables in non-classroom locations, for example by measuring the intensity of sound in a discotheque or the acceleration of a vehicle. These possibilities generate interest in measuring and meeting the physical world around them, besides the traditional classroom formats. It is therefore considered that the incentive of using smartphones in education encourages an interest in science in general.

We expect, as cell phones change our way of life, they will also change our way of teaching and learning. In this paper, the use of a smartphone is proposed for making direct measurements of the acceleration and the angular velocity of a physical pendulum. According to the initial conditions, the pendulum can be rotating or oscillating. The temporal series of the measured magnitudes allow these different motions to be distinguished. In addition, derived magnitudes as the kinetic and potential energies are also calculated and their relative extrema interpreted in terms of the characteristics of the motion. The comparison between the measures obtained by the different sensors (acceleration and rotation) and using traditional methods exhibits great coherence.

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ISSN: 2277-9655
(I2OR), Publication Impact Factor: 3.785

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