

Chapter XX

Smartphones in Engineering and Physics Education

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The accelerometer and gyroscope in smartphones were employed in an engineering and physics laboratory setting to measure the centripetal acceleration and angular velocity of a smartphone secured to a rotating platform. As is well-known, smartphones are ubiquitous on college campuses. These devices have a raft of built-in sensors. This creates a unique opportunity for a new paradigm in the physics and engineering laboratory. Many traditional physics and engineering experiments can now be performed very conveniently in a pedagogically enlightening environment while concomitantly reducing the laboratory budget substantially by using student-owned smartphones.

INTRODUCTION

Smartphone ownership has grown exponentially [1, 2]. However, the use of these devices in education is still lagging far behind. This paper is written to increase the awareness among educators of a timely opportunity to incorporate their use in the physics and engineering curriculum [3, 4, 5]. As an example of the multifarious applications of smartphones in our engineering and physics curriculum, we demonstrate how to measure the centripetal acceleration of a spinning smartphone on an inexpensive turntable. The measurements are made by recording the output from the accelerometer and the gyroscope within the smartphone. The software (“app” or application program) needed to record the output of these sensors does not entail any additional cost and we have set up a website for free downloads (<http://smartphonephysics.com>).

EXPERIMENTAL PROCEDURE

An old-fashioned LP turntable was acquired very inexpensively (Jensen 3-speed turntable with AM/FM Stereo Radio for less than \$50 from Amazon) and used as a rotating platform. Three rotational velocities of 33 rpm, 45 rpm, and 78 rpm were available. A student

45 rpm and r =7 cm.		45 rpm and r =12 cm.		78 rpm and r =7 cm.		78 rpm and r =12 cm.	
a_x (m/s ²)	ω_z (rad/s)	a_x (m/s ²)	ω_z (rad/s)	a_x (m/s ²)	ω_z (rad/s)	a_x (m/s ²)	ω_z (rad/s)
1.49	4.74	2.60	4.72	4.62	8.25	7.94	8.28
1.49	4.80	2.60	4.78	4.64	8.22	7.98	8.26
1.44	4.79	2.63	4.79	4.62	8.26	7.97	8.21
1.48	4.74	2.57	4.75	4.61	8.24	7.86	8.26
1.47	4.73	2.64	4.72	4.65	8.21	7.99	8.20
1.51	4.72	2.60	4.72	4.66	8.28	7.95	8.24

TABLE 1
ACCELEROMETER AND GYROSCOPE MEASUREMENTS MADE WITH A SMARTPHONE ON A TURNTABLE

provided smartphone was secured on an old-fashioned vinyl record by means of a masking tape (Figure 1). The record button on the app (The software, “app” or application program) was pressed and the turntable was turned on subsequently and almost simultaneously. The time delay does not have a deleterious effect on the integrity of the measurements, as the following discussion will convince the reader. The accelerometer and gyroscope outputs from the smartphone (among several other outputs, such as magnetic field, which are not directly relevant to the present discussion) were recorded by the app for ten seconds.

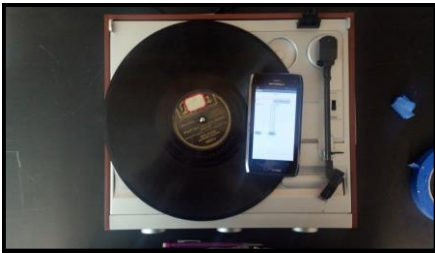


FIGURE 1
SMARTPHONE SECURED ON AN OLD-FASHIONED TURNTABLE

EXPERIMENTAL DATA

The accelerometer and gyroscope data for 45 rpm and 78 rpm for two different positions of the accelerometer (r = 7 cm. and r = 12 cm.) are tabulated for your viewing pleasure. In order to obtain the two different values of r , the smartphone is rotated 180° about the z-axis as elaborated in the subsequent discussion.

EXPERIMENT MEETS THEORY

The tabulated experimental data compares very favorably with the theoretical prediction. An angular velocity of 45 rpm corresponds to 4.71 rad/s and 78 rpm corresponds to 8.16 rad/s. The radial or centripetal acceleration, calculated most directly by using the equation $\mathbf{a} = \omega^2 \mathbf{r}$, for 45 rpm and $r = 7$ cm. is 1.55 m/s², for 45 rpm and $r = 12$ cm. is 2.66 m/s², for 78 rpm and $r = 7$ cm. is 4.66 m/s² and for 78 rpm and $r = 12$ cm. is 8.0 m/s².

THERE'S AN APP FOR THAT!

Fortunately, all apps that we need for our purposes are free. We have made these apps conveniently available for your download. Please visit the url <http://smartphonephysics.com>. The apps are available for Androids as well as the iPhone. We have also developed our very own accelerometer app for the Android operating system by using the MIT App Inventor. The advantage of this app is its simplicity and accessibility. The accelerometer output is immediately displayed on the smartphone screen (Figure 2). No muss, no fuss. The other apps on our website are more versatile in that they record the output from all the sensors (including the gyroscope) but the output is saved in text format as a .txt file on the iPhone and a .csv file on Androids. We recommend the app "Crossbow xsensor", for iPhone users and the app "AndroSensor" for Android users. The text files generated by these apps can be conveniently emailed to yourself. These are space delimited or comma separated values text files that look cluttered to the uninitiated. However, open this text file in Excel and in three clicks of the mouse, the Excel wizard will neatly arrange the data into columns.

LOCATION OF THE ACCELEROMETER

The accelerometer's exact location inside the smartphone determines the value of r shown in the data table. An alert reader may have wondered how conveniently the location of the accelerometer inside the smartphone can be ascertained. The traditional procedure is to pore through schematics. We have found a more ingenious solution that is also pedagogically rewarding. We perform two sets of experiments at the same rpm of the turntable. In one of these two sets of experiments, the smartphone is rotated 180° about the z-axis. The z-axis is perpendicular to the rectangular display of the

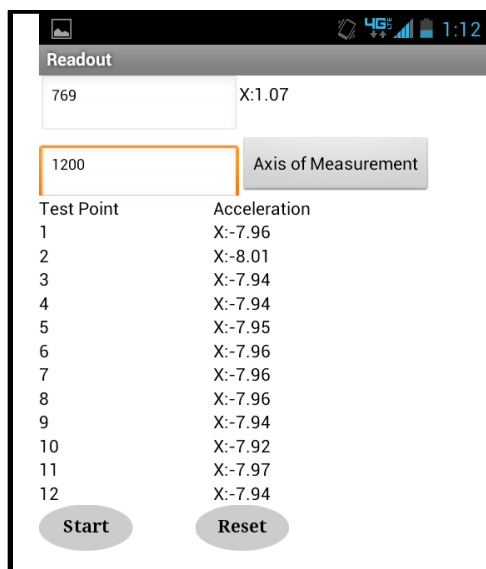


FIGURE 2

SCREENSHOT OF A SMARTPHONE DISPLAYING THE OUTPUT OF THE ACCELEROMETER

smartphone. The x-axis is along the shorter side and the y-axis is along the longer side of the rectangular display screen of the smartphone. The centripetal acceleration depends on the distance of the accelerometer from the axis of rotation whereas the angular velocity output of the gyroscope does not. Consequently, this rearrangement does not change the output of the gyroscope but clearly changes the output of the accelerometer. This is because the accelerometer is not in the center of the smartphone. It is, in fact, located at the bottom right corner. This helps us pin down the exact location of the accelerometer inside the smartphone.

OUTPUT OF THE GYROSCOPE

The gyroscope inside the smartphone is a microelectromechanical systems (MEMS) version of the vibrational gyroscope fabricated by STMicroelectronics [6]. The gyroscope data includes the traditional roll, pitch, and yaw in addition to the angular velocity (in rad/s) along the x, y, and z axes. The smartphone has a rectangular profile. The long side of the screen of the smartphone is the y-axis and the short side is the x-axis. The z-axis is perpendicular to the screen as well as to the x and y axes. The roll is a rotation about the y-axis, the pitch is a rotation about the x-axis and the yaw is the rotation about the z-axis. Both the accelerometer and the gyroscope inside the smartphone are triple-axis devices. Note that all smartphones have the accelerometer [7]. All iPhones have the gyroscope, in addition to the accelerometer. Some older model Android smartphones do not have the gyroscope. The angular velocity about the z-axis, ω_z (rad/s), or the rate of change of yaw, is the quantity of relevance in the experiment described in this paper and is depicted in the data table. A comparison of our data in Table I, with the calculations under the section titled “Experiment Meets Theory” above, reveals that the gyroscope output is very accurate and reproducible.

DISCUSSION AND SUMMARY

The smartphone is a robust and versatile device that can accurately, conveniently, and reproducibly measure physical quantities such as acceleration and angular velocity. This creates an opportunity for a new paradigm in physics pedagogy. Student-owned smartphones can conveniently be implemented in the physics and engineering laboratory while concomitantly reducing the laboratory budget. We have found that students take enormous pride in the data generated by their smartphones and are excited and motivated to learn from them. We even let them take their newfound physics toy home with them!

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Taylor Sinatra is a graduate of Salisbury University's physics program. He focused on microelectronics and has a strong drive to apply innovative techniques to modify traditional paradigms in physics and engineering education.