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Analyzing free fall with a smartphone acceleration sensor

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The column features short papers (generally less than 1000 words) describing experiments that make use of the sophisticated capabilities of mobile media devices produced by various manufacturers. Each month, in this space, we will present examples of how students can use (often their own) devices to investigate interesting and important physical phenomena. We invite readers to submit manuscripts to the column editors. The contributions should include some theoretical background, a description of the experimental setup and procedure, and a discussion of typical results. Submissions should be sent to the email address of the column editors given above. We look forward to hearing from you.

This paper provides a first example of experiments in this column using smartphones as experimental tools. More examples concerning this special tool will follow in the next issues. The differences between a smartphone and a "regular" cell phone are that smartphones offer more advanced computing ability and connectivity. Smartphones combine the functions of personal digital assistants (PDAs) and cell phones.

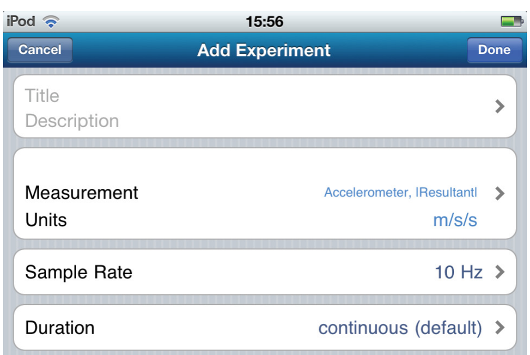

Fig. 1. Screenshot from the app SPARKvue, showing the setting of the experiment.

Smartphones are usually equipped with a microphone alongside a number of other sensors: acceleration and field strength sensors, a density of light sensor, and a GPS receiver. As all the sensors can be read by appropriate software (applications, or "apps"), a large number of quantitative school experiments can be performed with smartphones. This article focuses on this subject, providing suggestions on how a smartphone can be used to improve mechanics lessons, in particular when

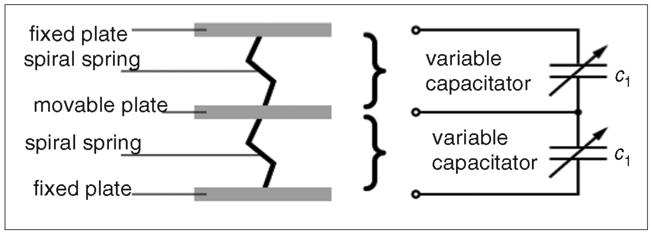

Fig. 2. Design and mode of operation of acceleration sensors.[5]

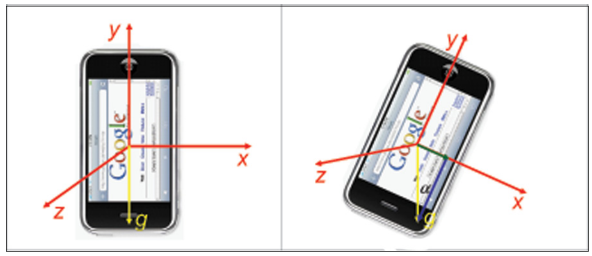

Fig. 3. The orientation of the three independent acceleration-sensors of an iPhone or iPod touch; the sensors measure the acceleration in the direction of the three plotted axes.

used as an accelerometer in the context of laws governing free fall.[1] The app SPARKvue[2] (see Fig. 1) was used together with an iPhone or an iPod touch, or the Accelogger[3] app if an Android device was used. The values measured by the smartphone were then exported to a spreadsheet application for analysis (e.g., MS Excel).

Mode of operation of acceleration sensors in smartphones

It makes sense to fundamentally understand how acceleration sensors work before using them in the classroom. Smartphone acceleration sensors are microsystems that process mechanical and electrical information, so-called micro-electro-mechanical systems (MEMS). In the simplest case, an acceleration sensor consists of a seismic mass that is mounted on spiral springs and can therefore move freely in one direction. If an acceleration a takes effect in this direction, it causes the mass m to move by the distance x. This change in position can be measured with piezoresistive, piezoelectric, or capacitive methods and is a measurement of the current acceleration.[4] In most cases, however, the measurement is made capacitively. Figure 2 shows a simplified design of a sensor of this kind:[5] Three silicon sheets, which are placed parallel to each other and connected with spiral springs, make up a series connection of two capacitors. The two outer sheets are fixed; the middle sheet, which forms the seismic mass, is mobile. Acceleration causes the distance between the sheets to shift, leading to changes in capacity. These are measured and converted into an acceleration value. Strictly speaking, they are therefore not acceleration sensors but force sensors.

To measure acceleration three-dimensionally, three sensors have to be included in a smartphone. These sensors have

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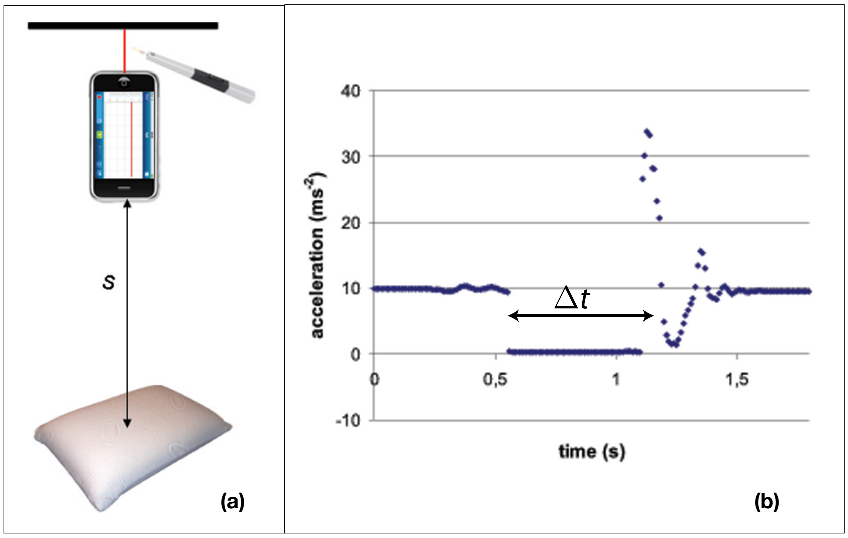

Fig. 4. Free fall: (a) Experimental setup and acceleration process. (b) Presentation of measurements after the export of data from the smartphone into MS Excel.

to be positioned orthogonally to each other and determine the acceleration parts a_x, a_y, and a_z of each spatial direction (x-, y, and z-axis) independently (see Fig. 3).

Study of free fall by a smartphone

A suitable way of examining free fall is to suspend the smartphone from a piece of string, which is burnt through to start the fall [see Fig. 4(a)]. In order to avoid damaging the device, we place a soft object under the cell telephone (e.g., a cushion) for it to land on. After having started the measurement of acceleration with a measuring frequency of 100 Hz, we burn the string through and the free fall commences. The acceleration value measured can be seen in Fig. 4(b).

At first, the smartphone is suspended from the string and the acceleration of gravity of 9.81 ms^{-2} takes effect [left part of Fig. 4(b)]. After approx. 0.6 s, the free fall begins and the sensors cannot register any acceleration, because they are being accelerated with 1 g themselves.[6] This state is maintained until the cell phone's fall is stopped by landing on the soft object. As can be seen in Fig. 4(b), the sensor continues to move slightly and returns to complete immobility after a period of 1.5 s. The measurement can then be terminated and exported to a spreadsheet program (e.g., MS Excel) in order to determine the time it takes to fall Δt.

It is obvious that the smartphone has a dual function in this experiment. It serves both as falling body and as electronic gauge, making it possible to determine the free-fall time with a good degree of accuracy. For the measurement example described, the falling time was calculated to be $\Delta t = 0.56$ s for a falling distance of $s = 1.575$ m. If these values are applied to the distance-time equation for uniform acceleration (without initial distance and initial speed and with the influence of the gravitational field for acceleration)

$$s = \frac{1}{2} g t^2, \tag{1}$$

the acceleration of gravity g is calculated with the formula

$$g = \frac{2s}{t^2} = (10.0 \pm 0.2) \frac{\text{m}}{\text{s}^2},$$

delivering a sufficient degree of accuracy for school instruction.

References

1. Corresponding ideas were previously published in P. Vogt, J. Kuhn, and S. Gareis, "Beschleunigungssensoren von Smartphones: Möglichkeiten und Beispielexperimente zum Einsatz im Physikunterricht" (translated as "Acceleration sensors of smartphones: Possibilities and examples of experiments with smartphones in physics lessons") *Praxis der Naturwissenschaften - Physik in der Schule* (translated as *Practices of Sciences – Physics in Schools*) **7**/60, 15–23 (Oct. 2011).
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5. P. Schnabel, "*Elektronik-Kompendium*" (translated as "Electronic Compendium") (Keyword: MEMS- Micro-Electro-Mechanical Systems), www.elektronik-kompendium.de/sites/bau/1503041.htm (temporary web address).
6. This is difficult to understand for pupils because they perceive the exact opposite: At first, the device suspends motionless from a string and then falls, accelerating to the floor. This is why they can only understand the measured acceleration process if they have previously been instructed on the way acceleration sensors function. In addition, the learners' previous experience of being pressed to the floor in a lift accelerating downwards, and the resulting conclusion that one is weightless in a free-falling lift, can also help them understand the process.