Smart Phone MEMS Labs

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INTRODUCTION

Smart phones have many MEMS sensors inside them including, accelerometers, microphones, cameras, gyroscopes, temperature, humidity, magnetic field sensors and more. Apps can be obtained that will output these sensor signals..

APPS – FOR ANDROID OS

Andro Sensor – free
    Location, Accelerometer, Light Level, Magnetic field, Orientation, Proximity, Battery Status and Sound Level.
Sensor kinetics – free
    Accelerometer, Gyroscope, Magnetic Field, Temperature, Humidity, Proximity, Light and Pressure.
Wifi analyzer – free
    signal strength vs wifi channels
FrequeSee – free
    dB versus Frequency
Speed Gun
    uses camera to detect speed
Many More……

INTRODUCTION TO ACCELEROMETERS

Acceleration (a) is the term given to the condition where an object experiences a change in velocity (v). Objects of mass (m) experience a force (F) equal to m times a. (F = ma) Earths gravity exerts an acceleration on objects creating a force. The acceleration due to gravity (g) has been found to be $9.8 m/s^2$. Acceleration, velocity and position (x) of objects are related by the following equation:

$$a = dv/dt = d^2x/dt^2$$

Acceleration

Earths Gravity	**1g**
Standing on the moon	**0.16g**
Passenger Car in a Turn	**2g**
Indy Car in a Turn	**3g**
Bobsled in a Turn	**5g**
Human Unconsciousness	**7g**
Human Death	**50g**
Car Crash Survival	**100g**
Mechanical Watch	**5,000g**
Electronics in Artillery	**15,000g**
Haldron Collider	**1.9E8g**

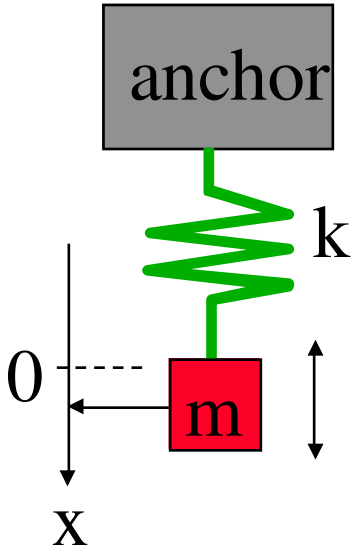
INTRODUCTION TO ACCELEROMETERS

An accelerometer is a sensor that can be used to measure acceleration. These sensors are used in systems for car air bag deployment, tilt sensing, and motion control. Most accelerometers are sensors that measure the force on a known mass (proof mass). The proof mass is supported by a spring, of spring constant (k), that will create a force equal and opposite to the force due to acceleration. The position is measured in response to changes in acceleration. There is also a friction or damping force.

$$F = ma$$

$$F = kx$$

$$m\, d^2x/dt^2 = kx$$



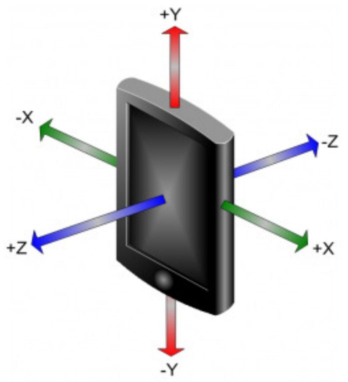
ACCELEROMETER EXAMPLE

Place your smart phone flat on a table. The x and y accelerometer outputs should read near zero, the z output should read near 9.8 m/s^2, the acceleration due to gravity.

Stand the phone upright on its bottom edge. The x and z outputs should read near zero, the y output should read near 9.8 m/s^2.

Stand the phone upright on its left edge. The y and z outputs should read near zero, the x output should read near 9.8 m/s^2.

Stand the phone upright on its right edge. The y and z outputs should read near zero, the x output should read near -9.8 m/s^2.



Accelerometer

Type: LIS3DH
Mfr: STMicroelectronics Ver: 1
Power Consumption: 0.011mA
Resolution: 0.020 Range: 39.227
Min Delay: 10000 μs

Rate: 100Hz
Units: m/s^2
Rate:FASTEST
X=0.0588
Y=0.1569
Z=10.0224

Gyroscope

Not available on this device

Magnetic Field

Type: AK8975
Mfr: AKM Ver: 1
Power Consumption: 6.000mA
Resolution: 0.301 Range: 1228.799
Min Delay: 20000 μs

Rate: 49Hz
Units: μT
Rate:FASTEST
X=10.199
Y=1.439
Z=-24.419

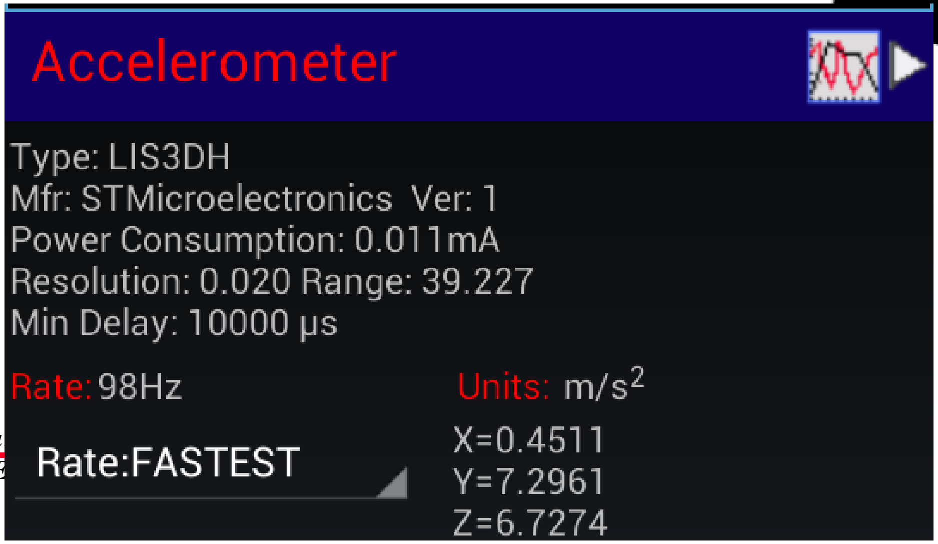
ACCELEROMETER EXAMPLE

Place your phone at a ~ 45 degree angle. Record the magnitude of the Ax, Ay, and Az acceleration vector.

Calculate the acceleration, A, using the following equation.

$$A = \sqrt{(Ax^2 + Ay^2 + Az^2\ )}$$

The acceleration on a stationary object is the acceleration due to gravity, 9.8 m/s^2.



Accelerometer

Type: LIS3DH
Mfr: STMicroelectronics Ver: 1
Power Consumption: 0.011mA
Resolution: 0.020 Range: 39.227
Min Delay: 10000 μs

Rate: 98Hz

Units: m/s^2

Rate:FASTEST

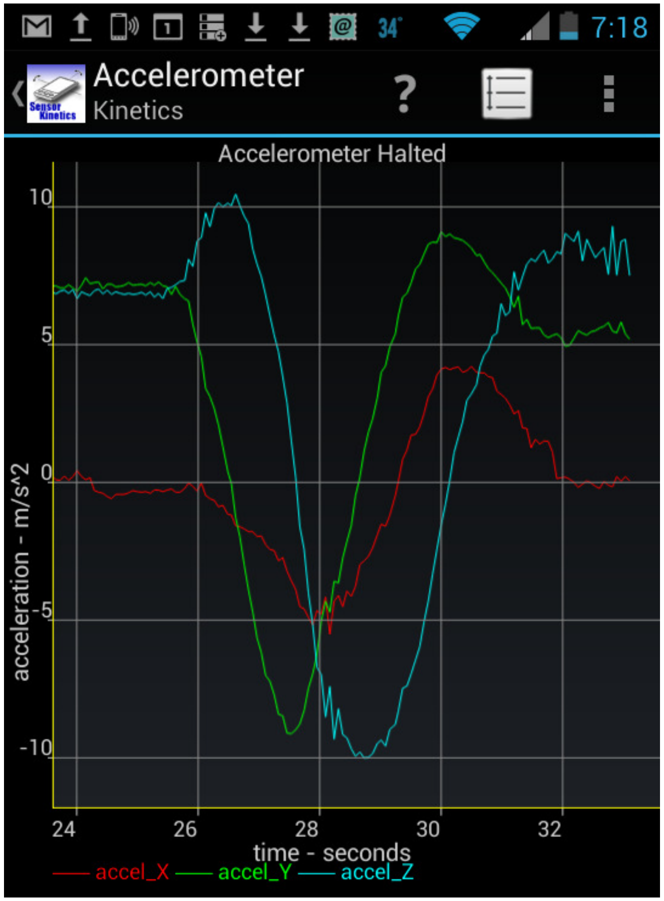
X=0.4511
Y=7.2961
Z=6.7274

ACCELEROMETER EXAMPLE

Set up your phone to give a plot of the Ax, Ay and Az output versus time. The vector sum of Ax, Ay and Az should equal ~ 9.8 m/s^2 at all times as you slowly rotate the phone in any direction.

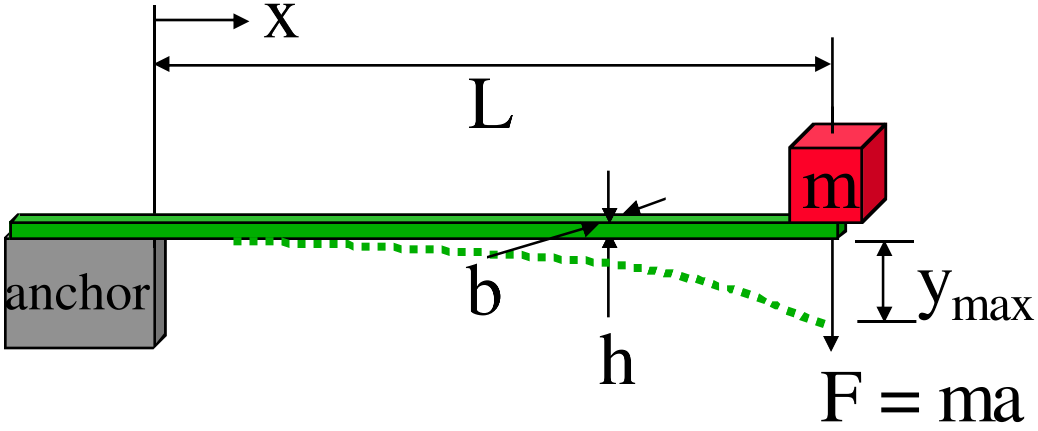
Calculate A at 24 seconds

Calculate A at 30 seconds



THE CANTILEVER BEAM

A cantilever beam (spring) with a mass (m) at the free end.



L = length of beam
b = width of beam
h = thickness of beam
y_{max} = maximum deflection

EQUATIONS FOR CANTILEVER BEAM

The maximum deflection at the free end of the cantilever is

$$\boxed{Ymax = F\,L^3/3EI}$$

where E = Youngs Modulus
and $I = bh^3/12$, moment of inertia
and F = ma

The resonant frequency (f_0) of the cantilever beam is

$$\boxed{f_0 = 1/2\pi\ \{3EI\,/\,(L^3(m+0.236m_B))\}^{0.5}}$$

where m_B is the beam mass and m is end mass
and E is Young's Modulus for beam material

Mechanics of Materials, by Ferdinand P. Beer,
E. Russell Johnston, Jr., McGraw-Hill Book Co.1981

EQUATIONS FOR CANTILEVER BEAM

We can write an expression for the position of the end of the cantilever beam after deflecting the beam by Ao and releasing.

$$X(t) = - Ao\ \cos\ (2\ \pi\ f_0\ t)$$

Taking the second derivative we write an expression for the acceleration experienced at the end of the beam on the test fixture.

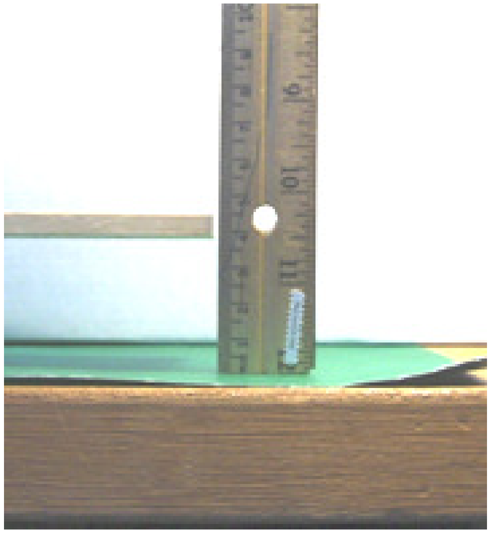
$$a = d^2X(t)/dt^2 = Ao\ (2\ \pi\ f_0)^2 \cos\ (2\ \pi\ f_0\ t)$$

ACCELEROMETER EXAMPLE

Set up your phone on a cantilever beam similar to the one shown. Using the equations shown above calculate the resonant frequency of the beam with your phone setting near the end of the cantilever. Set the beam in oscillation by pressing down on the end of the beam ~15mm and releasing, record the acceleration versus time. Extract Ymax, resonant frequency and maximum acceleration and compare to the calculated value.

Yard Stick $0.69, C-clamp $5.99 at Lowes

MEASUREMENT OF YMAX AND fo



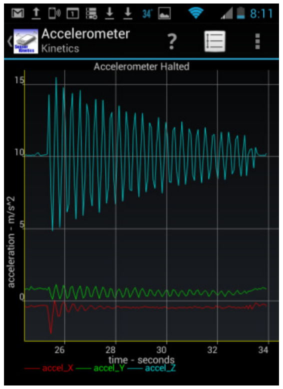
Y = ~ 39 mm

Y = ~14 mm

Movie

Record xyz acceleration versus time and extract resonant frequency

Ymax = 39 – 14 = 25mm



CANTILEVER BEAM CALCULATIONS

Example: Wood Beam h=5mm thick, B=36mm wide, L=0.56 meters long, Youngs Modulus, E= ~7.5 GPa, Wood density D = ~ 1.0 gm/cm3
phone mass is 126 gm, Ao = 15 mm

Calculated Ymax:

$$Ymax = F\,L^3/3EI$$

$$F = ma \quad I=bh^3/12$$

$$Ymax = \frac{(0.126Kg)(9.8m/s^2)0.56m)^3}{3(7.5E9\ Kg\ m/s^2/m^2)(.036m(.005m)^3)/12)}$$

$$Ymax = .0253\ m = 25.3\ mm$$

Calculated Resonant Frequency:

$$f_0 = 1/2\pi\ \{3EI\ /\ (L^3(m+0.236m_B)\}^{0.5}$$

$$m = .126\ Kg$$

$$mb = D \bullet Volume = 0.097Kg$$

$$fo = 0.159\left\{\frac{(3(7.5E9Kg\ m/s^2/m^2)(.036m(.006m)^3}{(0.56)^3(m+0.236\ mb)}\right\}^{0.5}$$

$$fo = 3.05\ hz$$

Calculated Max Acceleration:

$$a = Ao\ (2\ \pi\ f_0)^2$$

$$a = 0.015(2\ (3.14)3.05)^2\ \ m/s^2$$

$$a = 5.5\ m/s^2 \text{ above or below } 9.8\ m/s^2$$

CANTILEVER BEAM MEASUREMENTS

Measured Ymax:

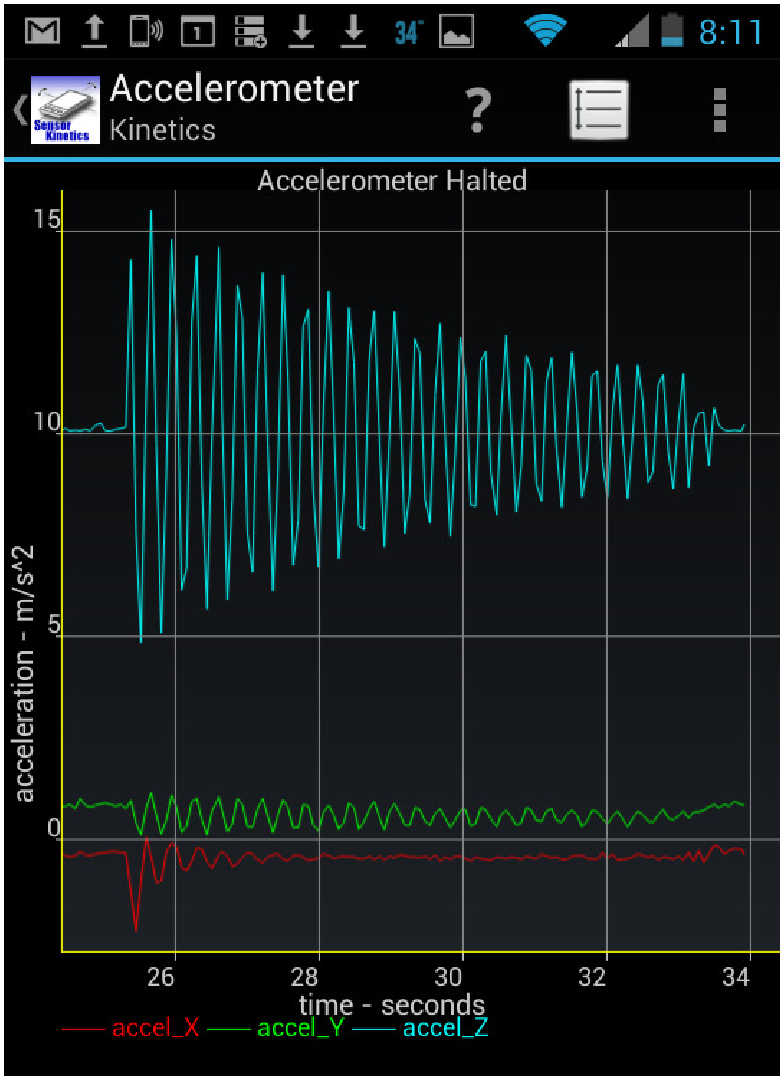
Ymax = 25 mm

Measured Resonant Frequency:

fo = 6.5 cycles/2 sec = 3.25 hz

Measured Max Acceleration:

Ao = ~ 5 m/s^2 above and below 9.8 m/s^2



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RESULTS

A comparison of the theoretical and measured values are shown below. The value for Young's modulus is approximate and if a different value is assumed the theoretical results will be different. The 7.5GPa is in the range given for various wood types.

	Theoretical	Measured
Ymax	25.3 mm	25 mm
fo	3.05 hz	3.25 hz
Max Acceleration	5.50 m/s^2	5 m/s^2

REFERENCES

1. Mechanics of Materials, by Ferdinand P. Beer, E. Russell Johnston, Jr., McGraw-Hill Book Co.1981, ISBN 0-07-004284-5

2. Dr. Fuller's lecture notes on Accelerometers: http://people.rit.edu/lffeee/eeee688.htm

HOMEWORK – SMART PHONE SENSORS

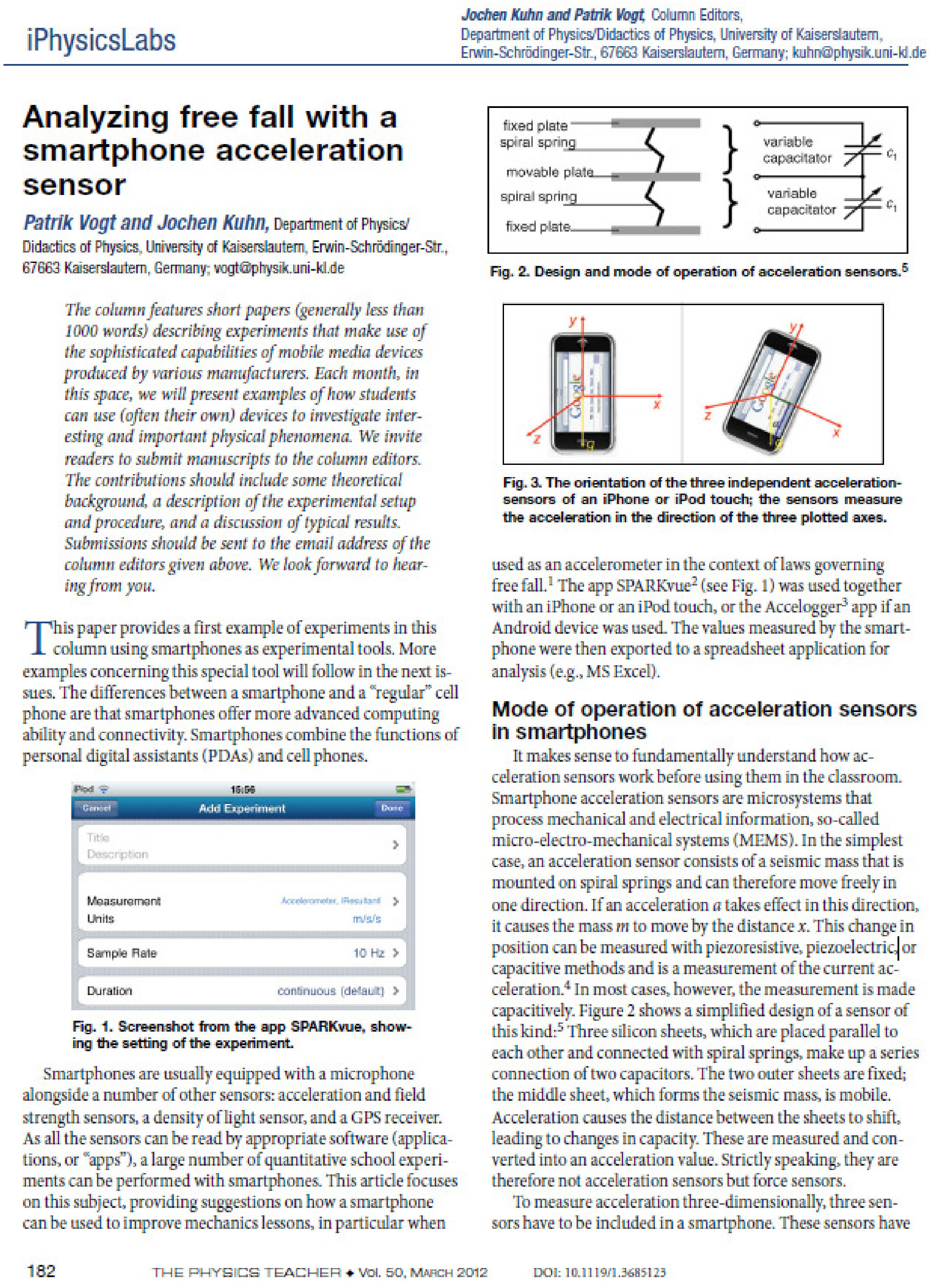
1. Use your smart phone to investigate MEMS devices and sensors. Repeat all the examples in this document with your phone.

2. Create an experiment (different from the ones in this document) based on one selected MEMS device in your smart phone. You are to write a technical document that includes an experimental procedure and your results. The experiment should use mathematics to theoretically predict the sensor output. Measure something and compare your results with theoretical.

(If you do not have a smart phone do a literature search on using smart phones for sensing, measurements and diagnostics. Write a one page summary of what you have learned. Attached a paper copy of your main reference)

Smart Phone MEMS Labs

EXAMPLE FROM THE LITERATURE



iPhysicsLabs

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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.

Title
Description
Measurement: Accelerometer, |Resultant|
Units: m/s/s
Sample Rate: 10 Hz
Duration: continuous (default)

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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EXAMPLE FROM THE LITERATURE

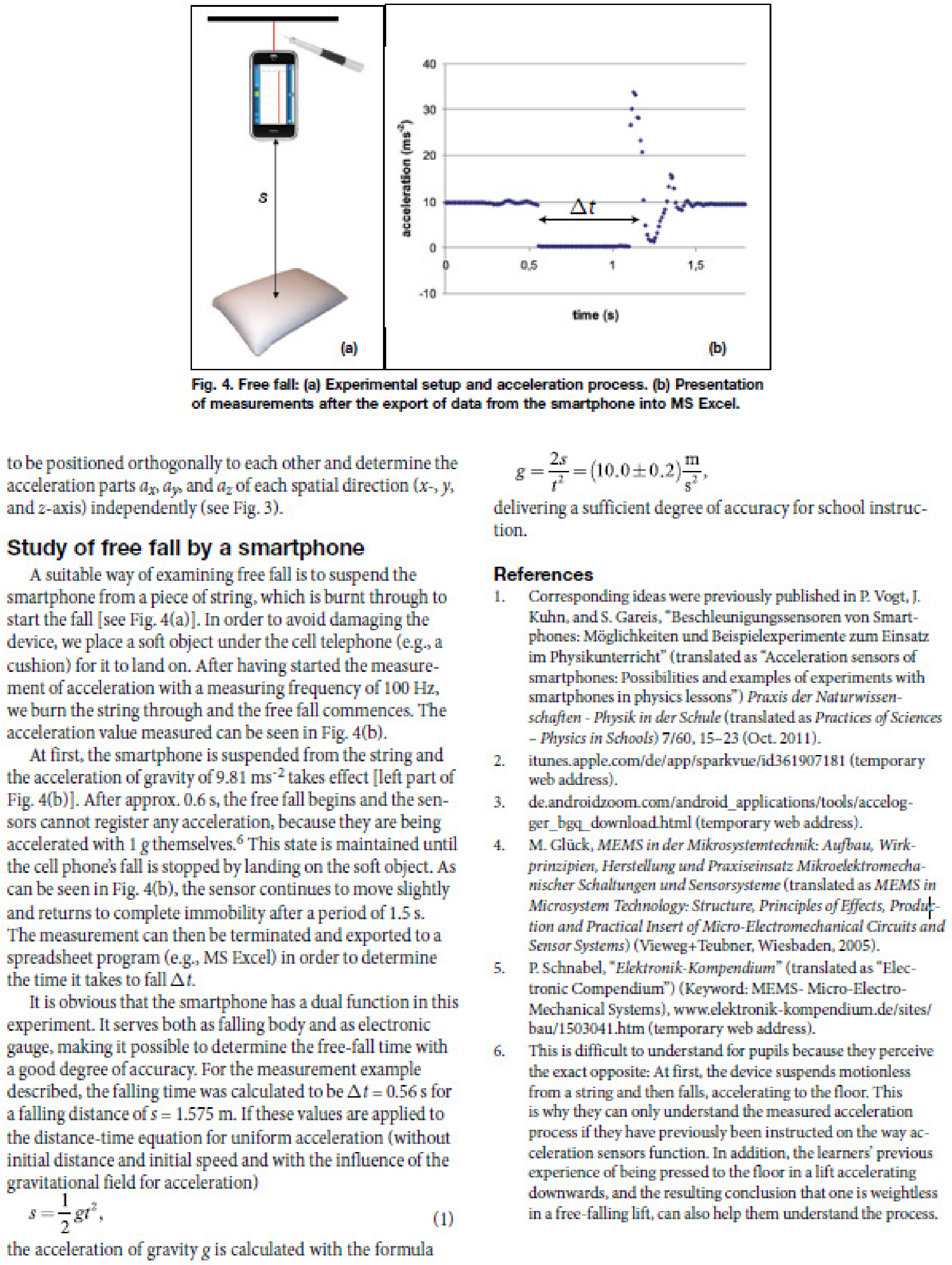

Fig. 4. Free fall: (a) Experimental setup and acceleration process. (b) Presentation of measurements after the export of data from the smartphone into MS Excel.

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)

$$s = \frac{1}{2} g t^2, \qquad (1)$$

the acceleration of gravity g is calculated with the formula

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

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).
2. itunes.apple.com/de/app/sparkvue/id361907181 (temporary web address).
3. de.androidzoom.com/android_applications/tools/accelogger_bgq_download.html (temporary web address).
4. M. Glück, *MEMS in der Mikrosystemtechnik: Aufbau, Wirkprinzipien, Herstellung und Praxiseinsatz Mikroelektromechanischer Schaltungen und Sensorsysteme* (translated as *MEMS in Microsystem Technology: Structure, Principles of Effects, Production and Practical Insert of Micro-Electromechanical Circuits and Sensor Systems*) (Vieweg+Teubner, Wiesbaden, 2005).
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.