A Smart Accelerometer

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1 | Summary

The motion sensors inside a smartphone allow students to measure the acceleration X in three perpendicular directions and thus can be useful for explaining how to resolve a vector into its components and their combination. Acceleration on a small scale can be demonstrated in the classroom using a record player (30 cm in diameter). It is very important to find the position of the accelerometer and take it into consideration when we investigate movements along a non-linear trajectory. Acceleration on a large scale can be seen outdoors on a rotating ride in an amusement park or a fairground (7.20 m in diameter).

- **Keywords:** acceleration
- **Disciplines:** physics, mathematics, computer science
- **Age of students:** 15-18 years
- **Android and iOS apps:** SensorKinetics, SensorKinetics Pro
- **Android apps:** Physics Toolbox Accelerometer, Accelerometer Monitor, Physics Toolbox Roller Coaster, Regression Calculator
- **iOS apps:** Sparkvue, Regression Calculator
- **Further software for computers:** Tracker

2 | Conceptual introduction

The students examine uniform circular motion in real contexts. They investigate the motion on a small scale using a record player. The sensor of the smartphone provides the values of acceleration along the three axes. Measuring the acceleration of the smartphone in different positions on the record player makes it possible to localise the sensor's position within the smartphone.

We present two measurement methods. Students can better understand the influence of the sensor's position by using an application for dynamic geometry.

The students can investigate circular motion on a large scale on board a rotating ride. They measure the acceleration with smartphones placed at different positions on the platform of the ride. They study the effect of the acceleration along the three axes. In particular, they focus their attention on the radial direction in order to better understand the centripetal acceleration.

Then they analyse the values obtained and insert them into a specific app on their smartphones. Using this app, the students trace the graph of acceleration versus radius, and they carry out a regression on the data. They find the equation of the linear fit, with slope and intercept, and evaluate the quality of this fit.

3 | What the students do

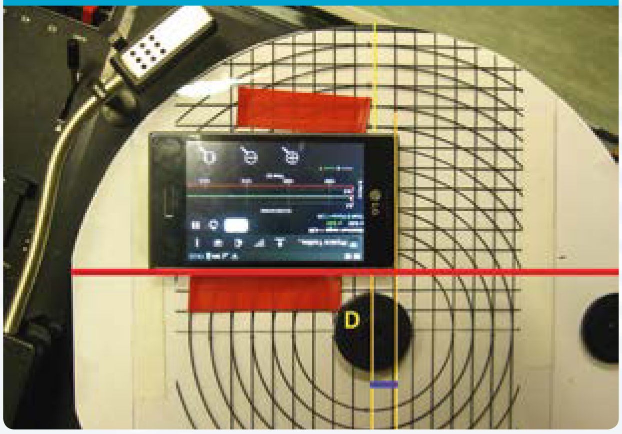
3 | 1 On a small scale (a record player or other small rotation device in the classroom)

3 | 1 | 1 Methods of measuring

The experiment could be set up as in **FIG. 1**. We record the videos and the acceleration using apps while spinning a smartphone on a record player.

The interpretation of the data and the calculation become easier when either pair of the smartphone's sides is aligned perpendicularly to the radius of the disk.

FIG.1 The disk with a transparent sheet simplifies the positioning of the smartphone



We can attach the smartphone to a transparent sheet with a piece of double-sided adhesive tape. This enables the accurate location of the smartphone in different positions along the chosen chord (the red coloured line in **FIG. 1**).

3 | 1 | 2 Simulation of movement with dynamic geometry

As seen in **FIGS. 1** and **2**, the smartphone revolves in the horizontal plane (the x-y plane) and therefore there is no Z component of acceleration. However, when the smartphone is placed vertically the X or Y acceleration can be omitted.

The application for dynamic geometry, i.e. Geogebra, makes it possible to change the positions of both the smartphone and the sensor within the smartphone and to plot the values of the acceleration components.

3 | 1 | 3 Collection and analysis of the data

[A] Students determine the position of the smartphone sensor during uniform circular motion. They move their smartphone along a fixed chord (the red coloured line in **FIG. 1**) and measure the acceleration for different positions (the blue coloured segment in **FIG. 1**).

The segment represents the distance between the diameter D and one side of the smartphone. When the students find the position where the tangential component of the acceleration is near zero, they have found the Y-coordinate of the sensor position.

In our experiments we measure the tangential, i.e. the Y-component of the acceleration, in ten different positions. Here we present three examples of the results.

The graphs and tables in **FIGS. 2, 3** and **4** show examples of results and calculations of average acceleration components vs. time.

The declared uncertainty of our sensor ("smallest scale division") is equal to 0.038 m/s² and in **FIG. 3** the measured Y-acceleration is smaller than this value, so we can consider it as the zero value and we can say that we have found the position of the sensor on the y-axis.

FIG.2 The side of the smartphone is 1 cm from the diameter D (*)

average acceleration a [m/s²]	speed up	rotation	slow down
a_y	0,39	0,718	0,58
a_z	-0,92	-1,779	-0,89
a_yz	1,00	**1,918**	1,06

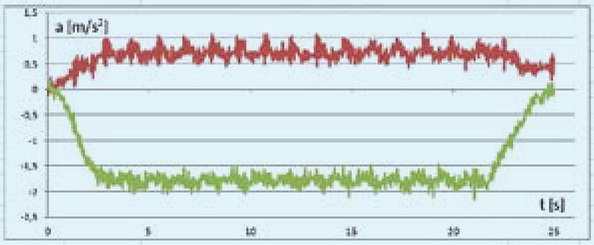


FIG.3 The side of the smartphone is 4 cm from the diameter D

average acceleration a [m/s²]	speed up	rotation	slow down
a_y	0,02	-0,030	0,05
a_z	-0,72	-1,830	-0,67
a_yz	0,72	**1,830**	0,67

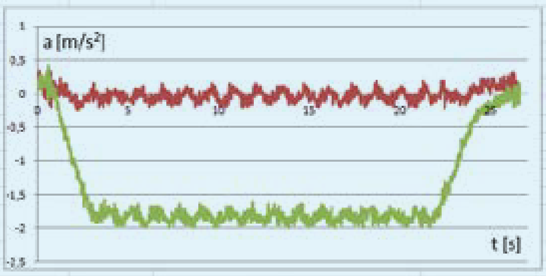
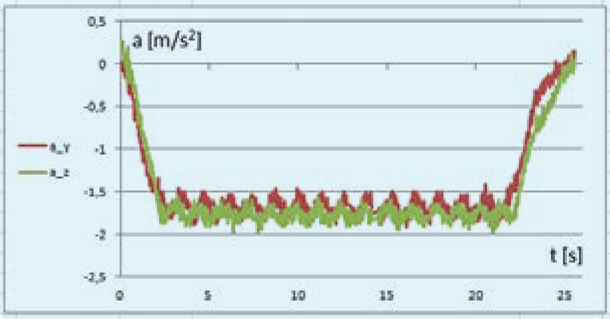


FIG.4 The side of the smartphone is 11 cm from the diameter D

average acceleration a [m/s²]	speed up	rotation	slow down
a_y	-0,89	-1,673	-0,67
a_z	-0,77	-1,773	-0,89
a_yz	1,17	2,438	1,12



Similar measurements made when the second pair of the smartphone sides is perpendicular to the radius enable the students to find the second sensor coordinate. Thus the sensor position is localised.

[B] Another method of finding a sensor position does not require getting zero for a chord tangential component of the acceleration. The distance R of the revolving sensor from a central axis can be calculated as follows:

$R = a / \omega^2$

where the acceleration "a" is derived from Pythagoras' theorem on the basis of the acceleration components measured

FIG.5 The centres of rotation C' and C" are the frames of reference for two positions of the smartphone on the record player

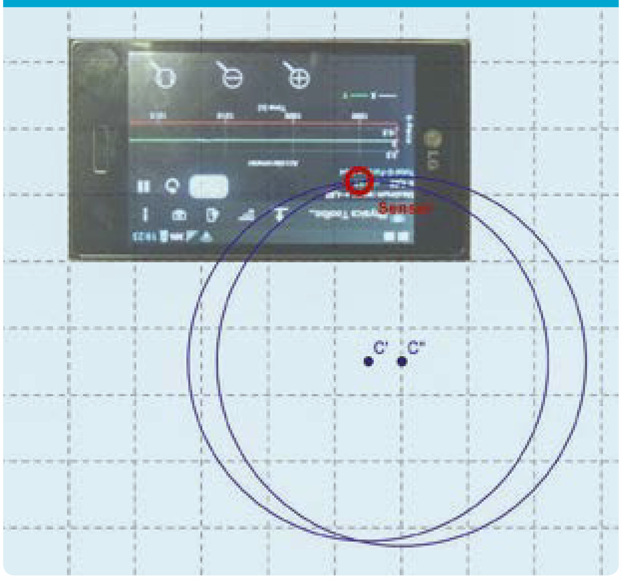


FIG.6 Setup of the experiment

FIG.7 Attach the smartphone accurately

by the sensor. We can estimate the angular speed ω from the frequency of the disk rotation or from video measurements, e.g. with the Tracker software. See also the "Spot the Physics" teaching unit in this brochure.

An example:
The acceleration components for the first setup are equal to a_x=0.128 m/s^2 and a_y=-2.435 m/s^2 and the circular motion period is T=1.31.s.

$a_x = 0.128\ m/s^2$

$a_y = -2.435\ m/s^2$

$a = \sqrt{a_x^2 + a_y^2} = 2.438\ m/s^2$

We calculate "a" from the formula above and finally R = 0.106 m.

We calculate the second radius for another position of the smartphone in the same way. **FIG. 6** portrays the position of the sensor as the intersection of the two circles whose radii were traced as above.

3|2 On a large scale (rotation ride in an amusement park or fun fair.)

3|2|1 Setup and measurements

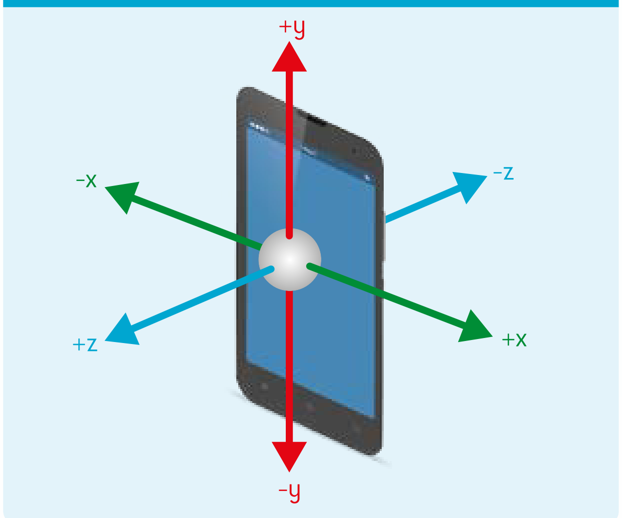
Find a rotating ride and look for a radial "corridor" on the platform, then fix and mark different points (P1, P2, P3, P4, etc.) with coloured tape along this radius. Measure the distance of each point from the ride's centre using a metric tape. If there are obstacles to direct measurement from the centre, measure the distance of each point from the external edge of the platform and calculate the difference from the platform radius.

Measure the period of the ride with the stopwatch of your smartphone, repeat the measurement and calculate the average value.

Run the app for the acceleration measurement and place the smartphone on one of the marked points, taking care to align the smartphone along the radial direction.

At the same time, other students could put their smartphones in other positions along the radius so that they can obtain more data simultaneously and record the data. They should align the y-direction of their smartphones with the radius of the ride.

FIG.8 Coordinate system of a smartphone



After the ride has stopped, the students should take a look at the graphs of the accelerations along the three axes x, y, z and observe the differences in detail.

FIG.9 Acceleration vs. time in the x-direction

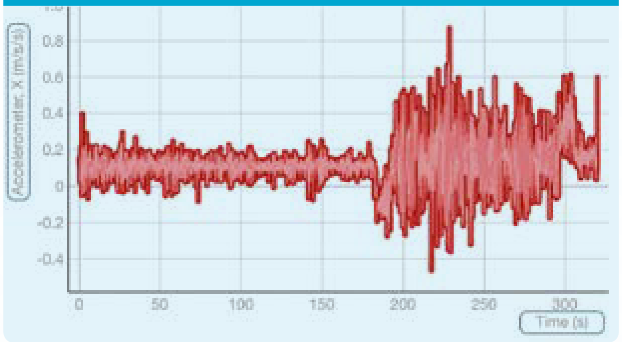


FIG.10 Acceleration vs. time in the z-direction

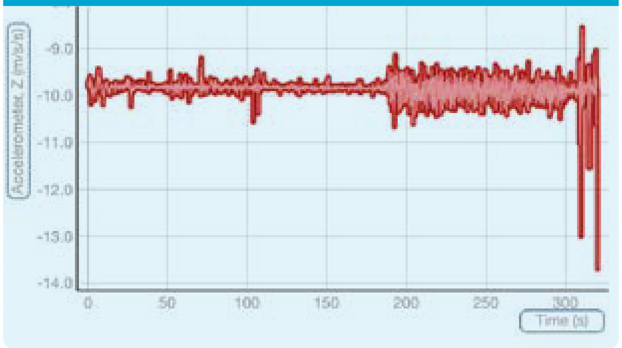


FIG.11 Acceleration vs. time in the y-direction with initialised offset, equal to -0.20 m/s/s

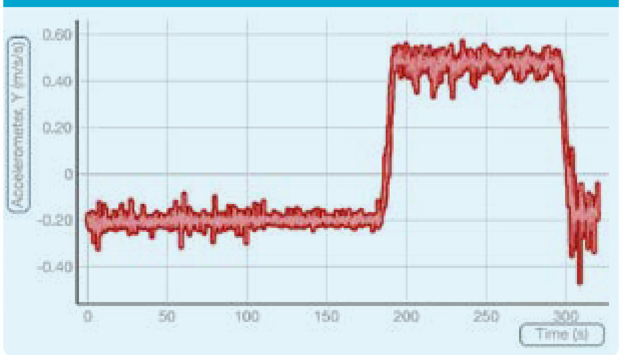


FIG.12 Acceleration vs. time in the y-direction without initialised offset

3 | 2 | 2 Analysis

The acceleration vs. time in the x-direction and in the z-direction is quite constant, but there is more fluctuation of the data in the state of motion than in the state of rest.

The charts show a typical measurement: when the ride begins to move, the acceleration along the y-axis increases (in a positive direction with respect to the positive y-direction of the smartphone (see the coordinate system of a smartphone above). After that, the acceleration is quite constant (the rotation speed is constant) and then, after the acceleration along the y-axis decreases, it returns to zero when the ride stops.

In one of the charts the initial value of acceleration, before the rotation, is not zero and the students have to subtract this value from the measured acceleration in order to obtain the real value.

The students can try a manual regression of the data. They must plot the points (radius, acceleration) on a graph and trace the best-fit line of data (linear regression) and find its equation: $y = mx+q$, with the slope and intercept.

The students can also use an app for regression on the smartphone to carry out the linear regression. In this case they must find the parameters of the equation and plot the data with the line.

The students can observe the value of R2 to decide the quality of the data fit. In the example shown, the result is excellent. At the end of the project, the students take the values of the acceleration they obtained with their smartphones, compare them with the theory (see the formula for centripetal acceleration) and check the level of agreement.

4 | Cooperation option

Students from different schools and countries can share and compare their results and activities.

In order to encourage teachers and students to apply the smart accelerometers, we also organise a competition involving physics measurements in amusement parks in collaboration with Science on Stage Europe and eTwinning France.

5 | Conclusion

The proposed activity is a good example for the students from the perspective of method. Since the physics of circular motion are always the same, the students have to deal with two situations that are subject to the same laws, but on different scales.

FIG.13 **Equation and quality of the linear fit**

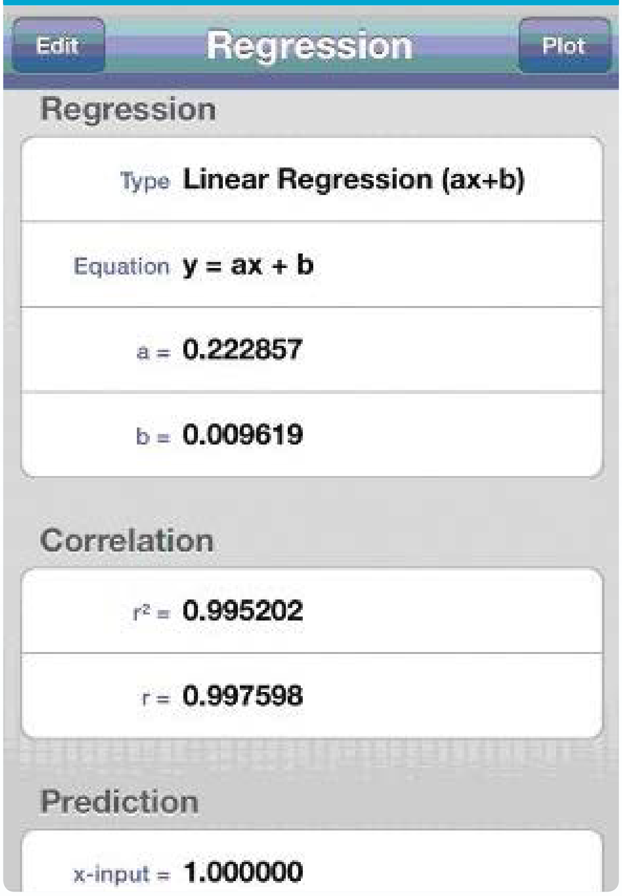
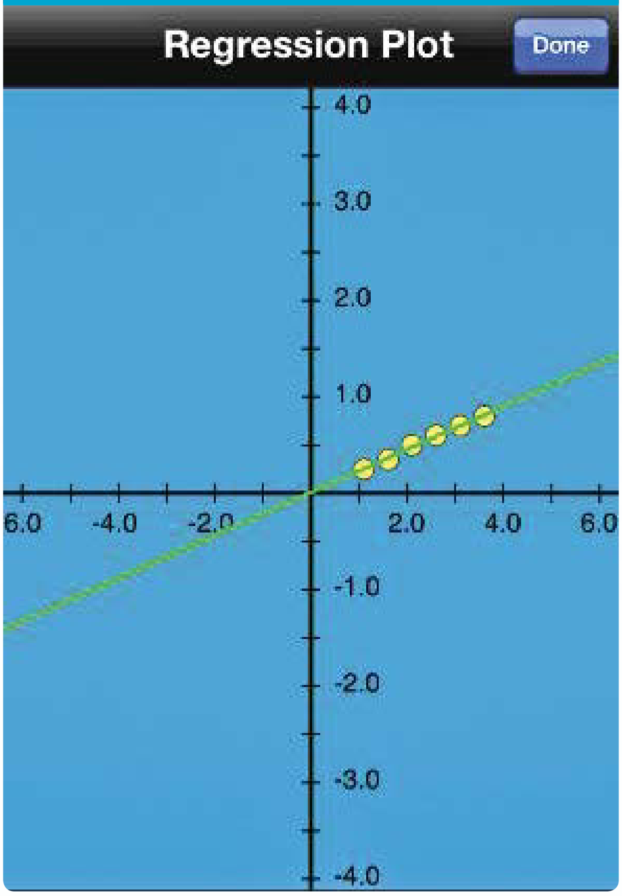


FIG.14 **Graph acceleration versus radius**



After highlighting the similarities, it is also important to highlight the differences between the two situations, for example the different degrees of importance of the accelerometer's uncertain position within the smartphone. This uncertainty, even if it involves several centimetres, is negligible when the dimensions are on the order of a few hundred centimetres (as in the radius of the ride), but it has a greater importance when the dimensions are comparable (as in the radius of the record player, about ten centimetres). There are many more situations in which students deal with circular motion in their lives, so they can also apply this experience to a merry-go-round, centrifuge, spin dryer, turntable, car/bike/train on a circular road, wheel, etc.

FIG.15 **Comparison of experimental and theoretical acceleration**

R (m)	a measured (m/s²)	a theoretical (m/s²)
3.60	0.80 ± 0.05	0.83
3.10	0.70 ± 0.05	0.71
2.60	0.60 ± 0.05	0.60
2.10	0.50 ± 0.05	0.48
1.60	0.35 ± 0.05	0.37
1.10	0.25 ± 0.05	0.25

6 | References

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