TURN YOUR PHONES ON: USING ANDROID DEVICES TO COLLECT SCIENTIFIC DATA

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ABSTRACT: Data logging devices have been in use for about three decades but they have never quite developed into the automatic choice of device for taking measurements in educational contexts. This article reviews the reasons for this, citing difficulties with setting up, dealing with the software, and overcoming hardware incompatibilities. The literature suggests that these factors have discouraged many science teachers from embedding data loggers into their teaching. Research by the industry shows that 80% of teenagers now possess Android devices in the form of a smartphone (cell phone) or tablet, and many schools have introduced schemes which supply pupils with their own tablet device for use in lessons. Android devices are now supplied with a range of sensors which can be relatively easily used for the capture of useful data in the Science laboratory. This paper evaluates four experiments carried out using a smartphone to collect the data. The experiments are described in detail, and the errors are analysed to evaluate the effectiveness and accuracy of the device in each experiment. The measurements were taken making use of Apps which were downloaded free of charge. The Apps were used in collecting data to measure audio frequencies, magnetic fields from an electromagnet, the acceleration of a moving body, and the coefficient of restitution of a bouncing ball. Data and images are presented to enable the audience to carry out and extend the experiments for their own use.

Key words: Smartphones, data logging, ICT, Android

INTRODUCTION

Computers were originally introduced into the UK curriculum in the early 1980s (although some had been in place earlier than that where schools were able to hire time on mainframes, e.g. at neighbouring universities). Since then as computers have increased in sophistication, speed and capacity, more and more educationalists have made use of them in their teaching.

The development of the personal computer since the 1970s has resulted in widespread use of computers in UK education after numerous policy initiatives from successive governments. However, Hammond (2014, 195) notes that while schools have invested in infrastructure, much of the investment has resulted in "an overemphasis on 'office' software". Policy and practice have therefore tended to lead away from the use of ICT in practical settings, while Wastiau et al (2013, 17) reports that "Digital resources such as … data logging tools … are still very rarely used by students during lessons".

However, Wastiau et al (2013) found that between 2006 and 2013, access to educational technology had roughly doubled, with broadband access available in 95% of EU schools. In the EU, there are approximately five pupils for every computer. More and more pupils are taking their own smartphones and tablets to school on a daily basis. For example, 65% of UK teenagers (age 12-15) have a smartphone (Ofcom, 2014).

While it is clear that the use of technology in science has not reached the saturation that might have been envisaged some years ago, when dataloggers were introduced, much time is spent, even in Science lessons, making use of computers as data searching or data analysis tools. But the use of computers for datalogging has been hampered by various issues – the rapid development of devices has led to compatibility problems, with new resources unable to make use of old software and vice-versa, and little research has been done to explore data logging practice, although Hammond (2014) asserts that while data logging devices allow for the capture of data in either difficult or remote circumstances, the exercise of data collection becomes an end in itself, rather than the analysis of the collected data being the focus of the exercise.

This article is not new in proposing the use of smartphones in collecting scientific data – see for example Monteiro et al (2016), Egri & Szabo (2015) and Patrinopoulos & Kefalis (2015). Smartphones now contain a range of sensors, enabling them to collect ambient data (temperature, humidity, pressure, light, sound level), as well as physical data (acceleration, magnetic field, sound frequency). However, most of these examples make use of in-house expertise in developing the necessary software to access the data. I was more interested in enabling students to obtain data free of charge, and without having to develop software skills that were not relevant to the subject being studied. I therefore explored application software (apps) which were available free of charge through either Google Playstore or Apple iStore. There are certain limitations involved, in that the apps are often produced without the detailed subject knowledge required to make sense of the data, and this can sometimes make the collected data difficult to record and analyse. However, final-year degree students studying Physics as part of their teacher training programme made frequent use of various apps when they completed a Physics investigation module. A high proportion of these students would use their smartphones first of all to take photographs of apparatus, and some discovered useful apps which enabled them to make use of their smartphone as the primary data collection instrument.

RESULTS

I describe here four experiments making use of some of the sensors available within most smartphones produced in the last five years, reviewing the experimenter's experience in collecting and analysing data. It was a precondition of the exercise to make use of apps that were generally available free of charge. The premise is that teachers might wish to encourage their pupils to use these apps for themselves, and a range of apps has been chosen to demonstrate how they might be applied across a range of abilities and ages. I then review some of the practices carried out be the final-year students in their Physics investigations.

The four experiments below have been chosen to provide a balance between 'quick-and-easy' experiments requiring little set-up, and those which require a degree of analysis before they can be utilised.

Magnetic Field

App: Physics Toolbox Magnetometer (Vieyra software)

At 11th grade (age 16-17), Physics students study the effect of magnetic fields on electron beams, and a classic experiment in this field uses a pair of Helmholtz coils to generate a suitable uniform field. The formula for this is beyond the scope of most courses at this stage, and yet it is usually quoted and used in order to calculate the value of the field used in the experiment. Here, I used the Magnetometer app to measure the field between a pair of Helmholtz coils, and compared it with the value calculated from the formula (see appendix for further details).
A screenshot of the display is provided below.
Calculated value: $4.17\pm.05\text{x}10^{-3}$ T
Measured value: $4.16\pm.04\text{x}10^{-3}$ T

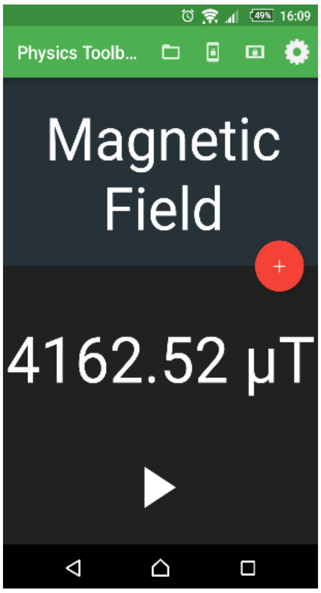

Figure 1. Screenshot from Magnetometer app

Discussion

The app is very easy to use; the only issue is determining the limitation of the sensor when its value is displayed to six significant figures. I took the uncertainty to be of the order of the Earth's magnetic field, which is approximately 40 μT. It also takes a few moments to identify the best position to hold the smartphone in order to take the optimum reading – this will vary with the position of the sensor within the smartphone used. Accuracy appears to be very good.

Heart rate

App: Unique Heart Rate Monitor (Meet Your Need Production). This is a very straightforward standard experiment which can be carried out in classrooms to investigate the effect of various factors (e.g. exercise, caffeine intake) on heart rate.

This experiment is very simple to set up and run: heart-rate readings were taken every minute or so before, during and after drinking a cup of strong coffee. The app measures heart rate using its camera and lamp to detect light reflected from a fingertip – presumably detecting changes in the blood flow.

The graphing is not ideal, since it simply records values in the order they are taken. These can easily be transferred to a spreadsheet and displayed as below:

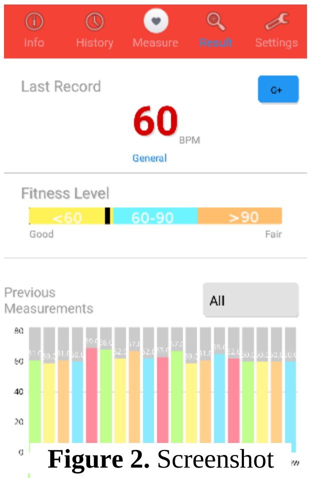

Figure 2. Screenshot from Heart Monitor App

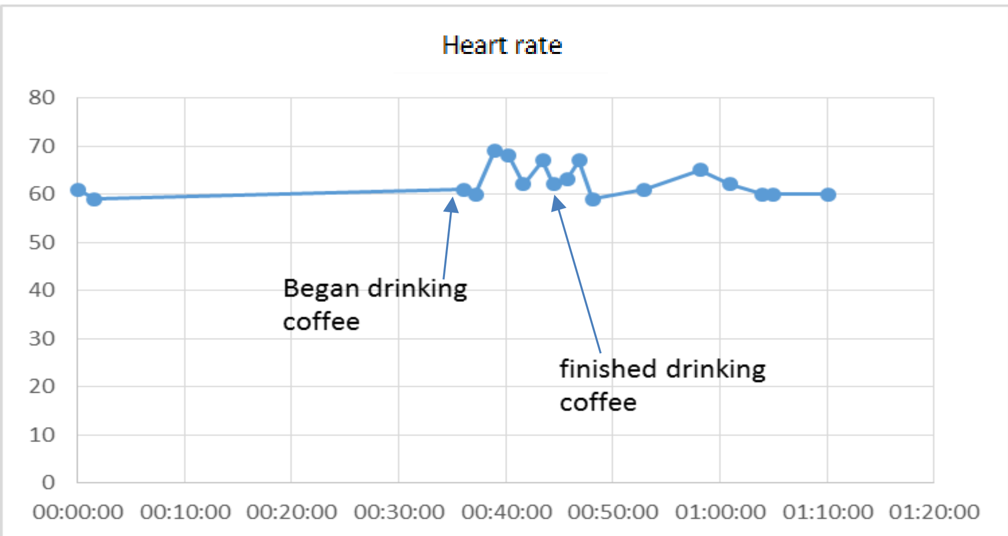

Figure 3. Graph of heart rate against time

Discussion

Data must be recorded by hand (or each reading could be recorded on a spreadsheet running on the smartphone). The app is sufficiently sensitive to demonstrate some effect from the drink, although more work would need to be done to confirm this. It is not clear whether the changes to heart rate are a result of the drink, or the effect of the experimenter's anxiety to produce results! An alternative would be to perform some simple exercise such as walking up a flight of stairs.

Ball Bouncing

App: Ball Tester (Solbacca) This app uses the sound detector in the smartphone to test the resilience of a ball. In this case a tennis ball was used, but the app allows for other types. It has been written to test balls from various sports against that sport's governing body regulations. By timing the gaps between successive bounces, the software is able to calculate the coefficient of restitution. Most governing bodies require that balls dropped from a specified height most bounce to a level within a given range. This app has taken the information from these regulations so that the data can be used to determine whether the ball meets the regulations.

In the reading displayed here, a previously unused tennis ball was dropped from close to the regulation height onto a solid floor. Figure 4 shows that the ball bounced to a height within the regulations (at the top end). It takes only a little practice to arrange for the ball to fall from a suitable height, although in actual fact providing that the app is able to record at least three bounces, it is able to calculate the coefficient of restitution. According to ITF regulations (ITF 2016) the ball must bounce to within 1.35-1.47m after being dropped from a height of 2.54m. This represents a range of values for coefficient of restitution between 0.73 and 0.79.

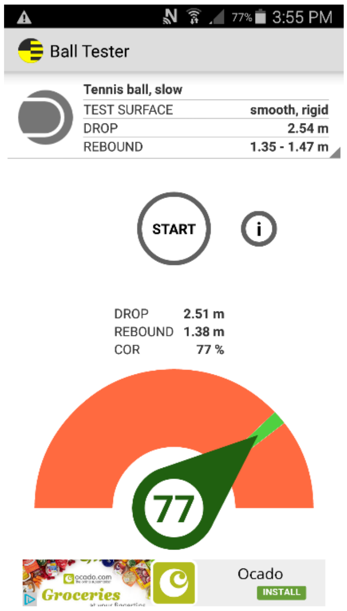

Figure 4. Screenshot from the bounce of a tennis ball

Discussion

The value calculated here ('77%') does not quite match the data displayed. These figures yield a value of 0.74 (see appendix), an error of about 5%. It is probable that the software calculates the coefficient of restitution directly from the time intervals between successive bounces, and that the displayed value of 77% (or 0.77) is derived from these figures. The error may due to the value of g used in the calculation, which is not stated in the app's documentation.

This exercise would prove useful to a group of students covering a mechanics course at about grade 11 requiring detailed use of equations of motion to derive the necessary formulae. Comparing the data with that collected using a stopwatch or timing gate would be interesting.

Measuring Acceleration

App: Physics Toolbox Accelerometer (Vieyra software). The use of a smartphone as an accelerometer is an inviting proposition – there are many situations in which data can be collected – for example in lifts, cars and aeroplanes. The software gives instantaneous values of acceleration or g-force in each of the three dimensions. In effect, in g-force mode the device is acting as a levelling instrument as it gives a constant value which alters as the device is tilted. In acceleration mode, it again gives values, this time in ms^{-2}, although these values flicker constantly as a result of random vibrations. The app also allows the user to record data through 'record' and 'stop' buttons. A graph of any or all for the values is displayed graphically as long as the phone is switched on. The time axis is updated continuously as the graph scrolls across the screen.

In this experiment, a dynamics trolley was accelerated along a friction-compensated runway by means of a force provided by a falling weight. (See figure 5). The acceleration of the arrangement was calculated from the size of the falling mass and from the mass of the combination. This was then compared with values obtained by the accelerometer app.

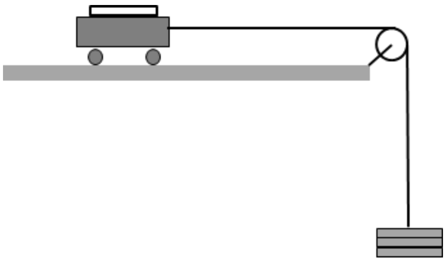

Figure 5. Experimental arrangement for measuring acceleration

With the mass of the trolley and smartphone reaching nearly 1kg, forces of 2N and 10N were used to accelerate the trolley. The smartphone was laid on a cushioning pad (bubblewrap) to absorb vibrations, and held in place with rubber bands to avoid the risk of throwing the phone and damaging it. Laying the phone horizontally meant that acceleration would take place in the y direction. x and z values should be zero. The smartphone was set up to record, released, and allowed to run into a barrier. Once the data file has been loaded into a spreadsheet, nul data either side of the journey can be discarded.

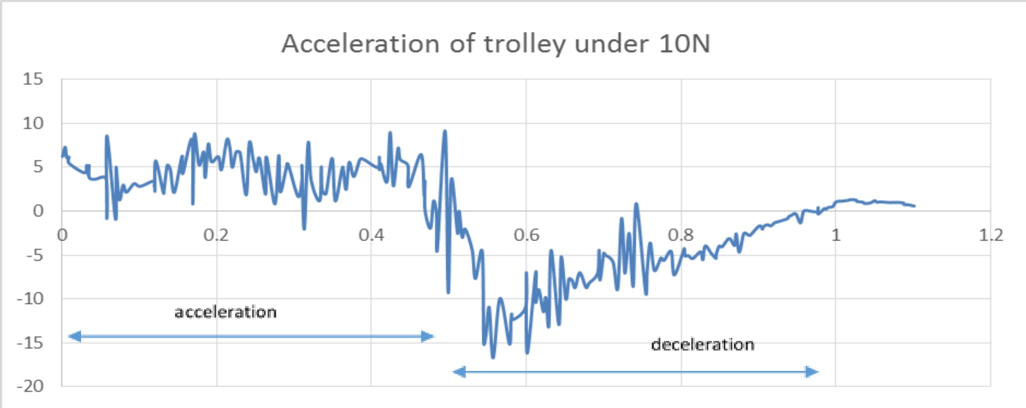

Figure 6. Graph of acceleration against time for moving trolley

Graphs of the data immediately show that there is a significant problem with vibration – the sensitivity of the device is so acute that the values from the vibrations tend to swamp the actual data, and although a value can be obtained which approximates to the predicted value, this can only be achieved after a significant amount of data manipulation, which undermines the task considerably. As can be seen in figure 6, the graph shows distinct phases of acceleration, deceleration and rest.

In the acceleration phase, there is significant vibration about the expected value of about 5ms^{-2}, and it will be noted that the standard deviation of the acceleration values is enormous, leading to a value with very little confidence. A number of techniques were tried to smooth the data, including moving averages, and eliminating extreme values, each of which brought the accelerometer value closer to the calculated value. (See appendix for further treatment)

Table 1. Comparison of measured and calculated values of acceleration for an accelerating trolley

Apparatus	Driving force (N)	Mass of trolley (kg)	Measured values				Calculated values
			Before smoothing		After smoothing		
			acceleration (ms^{-2})	Standard deviation	acceleration (ms^{-2})	Standard deviation	acceleration (ms^{-2})
Dynamics trolley	9.92	0.92	4.3	2.5	5.3	1.1	5.14
Dynamics trolley	1.95	0.92	1.3	1.8	1.7	0.5	1.74
Air track	0.243	0.29	0.8	0.5	0.9	0.3	0.77

The experiment was repeated with an air track. Because of the sizes of the apparatus, the driving force and masses were very much smaller than for the dynamics trolley, and even though the resulting graph was much smoother, because the values were smaller, the standard deviation of the results was still much too high.

Table 1 shows the values obtained from the accelerometer before and after data smoothing. The data smoothing had a mostly positive effect on the measured value of acceleration, and significantly improved the standard deviation. The most reliable result was, as might be expected, the first row, in which the driving force and resulting acceleration were quite high.

Discussion

Unfortunately, with this app the experiment became about the data manipulation and not about the experiment. Observed in other moving objects such as aeroplanes and lifts, the graphs produced by the app are swamped by vibrations. Other apps demonstrate the same difficulty and experimenters such as Egri & Szabo (2015), who describe a similar experiment on a trolley oscillating between two springs, accessed the data directly from the device. This was beyond the scope of this exercise, which has the aim of evaluating freely-available software. Close examination of the data shows that readings are taken in less than 1ms, and because the gyroscope is tiny, values from quite modest vibrations can be very high. To make better use of this sensor, it would be better to smooth the data on collection.

Summary of Investigations by Undergraduate Students

One of the final-year modules at Edge Hill University for trainee teachers undertaking a degree in Science (Physics) with Qualified Teacher Status is a Physics investigation. Students are invited to choose a topic to investigate, and many take advantage of the features of their smartphones to collect data. There follows a brief summary of some of the projects that have successfully been run.

Rotational Dynamics of Pool Balls

Software: Hudl (Ubersense) available from Apple iStore

In this investigation, the rotational and translational KE and momentum of a cue ball and object ball were measured before and after a collision. The slow-motion video of the interaction was analysed to measure the movement of the two striped pool balls. Figure 7 shows three stills from the motion of a cue ball (brown) which runs down a ramp at the top of the photograph, approaches the object ball, comes to rest in the same position as the object ball moves away, and then starts to move again as the rotational momentum is converted into translational momentum. The student was able to measure to a high degree of accuracy in order to account for the potential energy of the cue ball while it was held at the top of the ramp.

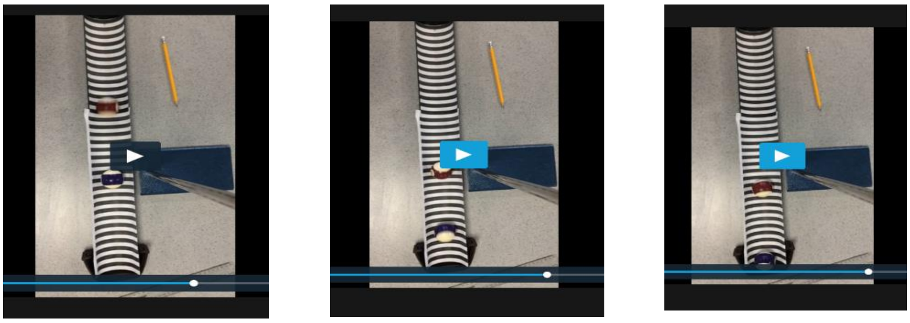

Figure 6. Motion of two striped pool balls as the cue ball (brown) approaches and strikes the object ball (blue)

Sound Frequency

App: Frequency Analyser v.1.2.04 (José Antonio Gómez Tejedo)

This student investigated the resonant frequency of wine glasses and needed a quick and accurate way of measuring the sounds generated. The Frequency Analyser app was tested and found to be accurate to at least 1% and enabled the student to quickly measure resonant frequencies.

Sound Levels

App: Decibel 10^{th} (SkyPaw)

To test the interference patterns generated by a surround-sound system, the student built a model studio in which four speakers were situated so that he could map the sound levels around the room. He was looking for the best part of the room to sit in and found that this varied according to the frequency of sound used. He used an iPhone, which was of a suitable size compared to the size of his model room, to record the data and he found that he could position the device systematically at evenly-spaced locations about the model.

Using Photography

App: camera supplied with smartphones, including video playback facility.

A significant number of students have used iPads or Android devices to analyse the motion of a variety of moving objects, including parachutes, bodies falling into water and toy electric cars. Analysing the motion of these bodies is made easy by taking freeze-frame images of the object as it reaches its highest/lowest point, and solving scaling problems to arrive at an accurate value for distances covered provide extra interest and challenge. Students also routinely take photographs of the apparatus they are using as the project develops so they are in a better position to recreate the arrangement week-by-week. Purists may prefer a return to reliance on line drawings, but for me there is significant experimental integrity to this technique, and encourages good experimental design and record-keeping.

CONCLUSION

There is at the moment no perceived standard for data logging in schools, and in Higher Education institutions data logging tends to be carried out by devices designed or programmed in-house. Apps provide a convenient, and for students, cheap alternative to solving some of the data collection problems they face. As a result, these students are encouraged to develop better experimental design, and to consider more closely the accuracy and reliability of the results they record. Data logging has often been seen as a means to an end, and the idea that the fundamental purpose of data loggers is to collect data where it is difficult or dangerous to do it manually. The experiments described here offer solutions where the data collection is otherwise problematic – generally because it is either inherently difficult for young people to carry out manually (e.g. heart rate) or because the observations are too rapid (experiments involving motion), or unnecessarily complicated (measuring as opposed to calculating magnetic field). Or because the smartphone is just so convenient and easy to use, (measuring sound levels, video recording). More to the point, students have these devices and love to be using them.

REFERENCES

Egri, S. & Szabo, L. (2015) Analyzing Oscillations of a Rolling Cart Using Smartphones and Tablets. *The Physics Teacher 53*, 162

Hammond, M. (2014) Introducing ICT in schools in England: Rationale and consequences. *British Journal of Educational Technology 45 (2),* 191–201, doi:10.1111/bjet.12033

International Tennis Federation (ITF) (2016) *Approval tests*. Retrieved May 16th 2016 from http://www.itftennis.com/technical/balls/approval-tests.aspx

Monteiro, M., Vogt, P., Stari, C., Cabeza C., & Marti, A. (2016) Exploring the atmosphere using smartphones. *The Physics Teacher 54*, 308

Ofcom (2014) *Children and Parents: media use and attitudes report.* London: Ofcom

Patrinopoulos, M. & Kefalis, C. (2015) Angular velocity direct measurement and moment of inertia calculation of a rigid body using a smartphone. *The Physics Teacher 53*, 564

Wastiau, P., Blamire, R., Kearney, C. Quittre, V., Van de Gaer, E. and Monseur, C. (2013) The Use of ICT in Education: a survey of schools in Europe. *European Journal of Education* 48, *(1),* 11–27.

APPENDIX: TECHNICAL DETAILS ON THE HARDWARE AND SOFTWARE

Smartphone used:
Sony Experia Z5 running Android version 6.0

Magnetic Field
App: Physics Toolbox Magnetometer v1.4.1 by Vieyra software

The Helmholtz coils are commonly available in UK schools with a radius and separation of approximately 7cm.

Formula used for calculating the field in a pair of Helmholtz coils:

$$B = \left(\frac{4}{5}\right)^{\frac{3}{2}} \frac{\mu_0 n I}{R}$$

Where $\mu_0 = 4\pi \times 10^{-7}$ TmA^{-1}
Values used here: n=320 turns; I=1.00±0.02A; R=6.9cm

The limitation appeared to be related to the steadiness of the current, and to the measurement of the diameter of the coils between the centres of the windings. Most apps are unable to deal with fields much higher than this. Some automatically cut out beyond about 5mT, others give false readings. In order to carry out a complete experiment with an electron beam, it may be best to measure B at a lower current than is used with the electron beam and scaling it up.

Calculated value of B = $4.17 \pm .05 \times 10^{-3}$ T
Value measured by App = 4162.52 μT, or $4.16 \pm .04 \times 10^{-3}$ T

Limitation: The Earth's magnetic field is approximately 40 μT. The number of significant figures displayed is unrealistic – three is the maximum allowable here.

The app is best used in 'total field' mode, where it combines the x, y and z components into a single reading.

Heart Rate

Software: Unique Heart Rate Monitor v1.26 supplied by Meet Your Need Production.

Data appears accurate to ±1, as compared with manual measurement.

Ball Testing

App: Ball Tester version 2.0.0 (Solbacca)

Allows testing of various types of sport ball, including tennis, golf and basketball.

For a ball dropped from a height H and returning to a height h, coefficient of restitution e is given by

$$e = \sqrt{\frac{h}{H}}$$

Using the equation

$$s = ut + \tfrac{1}{2}at^2,$$

it follows that for a ball starting from rest at height H and taking t_H seconds to reach the ground, it then bounces to a height h in t_h seconds. (The interval measured by the device = $2t_h$). The coefficient of restitution is given by

$$e = \frac{t_h}{t_H}$$

Hence the app is able to calculate e from the intervals between the second and third bounces (which are $2t_H$ and $2t_h$ respectively). It is likely that the app calculates e from these two values, and then works backwards to give values for h. The value of g used in the calculation is not given in the documentation.

Measuring Acceleration

App: Physics Toolbox Accelerometer v1.4.1 (Vieyra software)

The force provided by the falling mass m= mg

Slotted masses were used, and their masses were confirmed using an electronic balance. Thus, the force could be known to a high degree of accuracy (better than 1%). The expected acceleration was calculated for each journey using

$$a = F/M,$$

where M is the mass of the trolley/smartphone plus the falling mass.

Data were smoothed by eliminating extreme data. Results which were greater than double or less than half of the mean were ignored on the assumption that these were anomalous values caused by vibrations as the trolley travelled along the runway. The standard deviation and mean were retaken after this process.

The author is not well-versed in statistical smoothing techniques, so my apologies for any offence caused by this crude methodology! A simpler solution would be to design an app which smoothed the data at source.