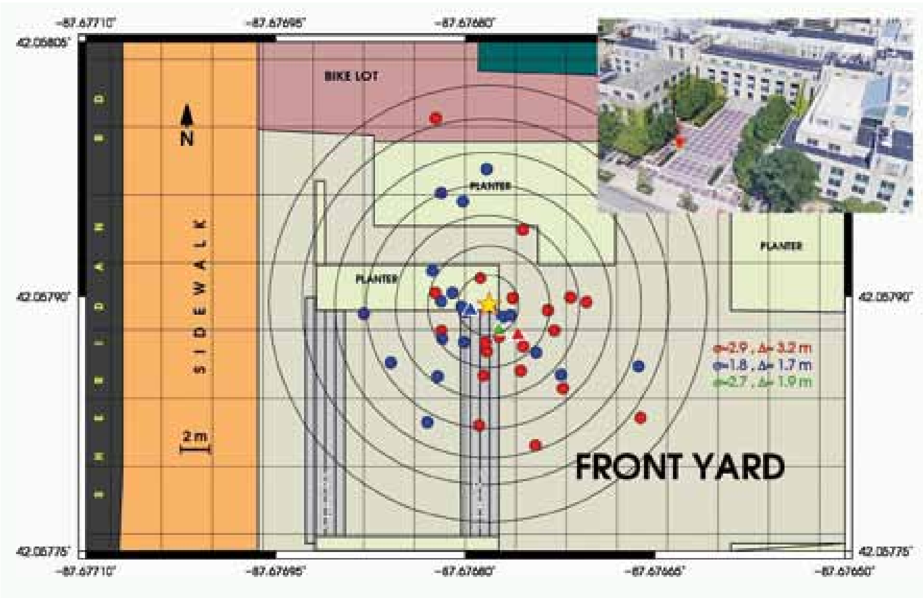
Turn your smartphone into a geophysics lab

Amir Salaree and colleagues explain how that smartphone in a student's pocket can be used to perform geophysics experiments.

Geophysics is fun to teach because of the many real-world examples that students can relate to. However, it is difficult to put good geophysics experiments together without expensive gadgetry and technical support, and many teachers will have thought, "Darn! I wish we could do that in class…"

We remember when we were students ourselves, walking around during lab sessions to find a free "station" to do an activity, because there were limited – often only one – pieces of equipment. We were also frustrated because we couldn't do things requiring greater technology. For instance, we measured the speed of P-waves in the Earth's crust using printed seismic sections from studies published by other people, giving little insight into the nuts and bolts of the actual data collection and recording process. Now, as teachers, many of us share the same thoughts: it would be great to have multiple sets of instruments and to be able to do something fancier in lab time. But until recently, getting enough GPS units, seismometers with digitizing units, gravimeters and digital thermometers for a lab required a pot of money.

One solution is to use smartphones. Students are already familiar – perhaps unduly so – with their smartphones. They can be used to do homework or make basic measurements (e.g. Armstrong 2014) that improve comprehension and motivate active learning (Bromley 2012). But they also have built-in instruments that can make useful measurements for geosciences: measurements that have been too expensive or simply impossible in the lab. Built-in GPS units, accelerometers and thermometers are used for phone operations such as navigation, screen rotation and personal customization of apps; data from these sensors are not necessarily displayed, but third-party apps can access and extract them (e.g. Griscom 2006).



1 Students measured values for latitude and longitude of the point shown by the red arrow (inset, from Google Maps). The map shows position measurements made by Android phones and iPhones (red and blue dots) with red and blue triangles showing the two groups' midpoints. The green triangle represents the halfway point of all the measurements and the yellow star shows the geospatial reference point from Google Earth. Contours are at multiples of 1 m from the reference point.

Three simple experiments illustrate how data from smartphone sensors can be useful in geophysics labs. We have developed these experiments to address the topics of positioning (accuracy and precision), seismic signals and gravity in an introductory geophysics course called Earth's Interior at Northwestern University, USA. The students are either from Earth sciences or engineering.

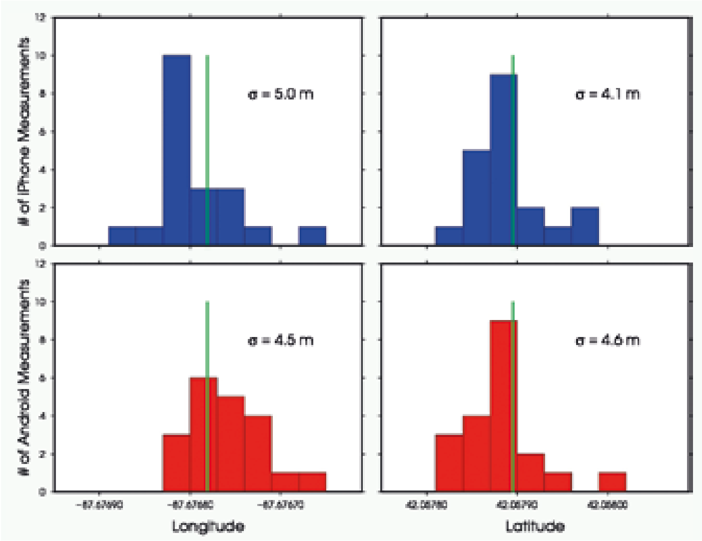
"The signals from the accelerometers in a phone turn it into a small seismometer"

Positioning – accuracy and precision

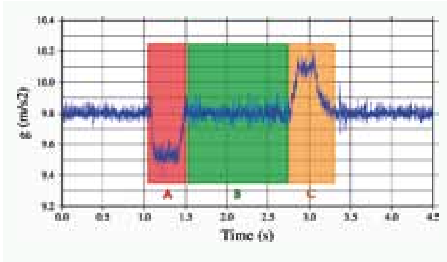
For the first experiment, exploring positioning, students used their phones to make measurements, at least six hours apart, of the latitude and longitude of the corner of a planter in front of a building (red arrow on figure 1). Then they extracted the coordinates using Google Maps, entered their results in a spreadsheet and sent it to the instructor. Figure 1 shows a cumulative dataset, with Android and iPhone data plotted in red and blue, showing a slight difference between the two. The midpoints from the two groups are more than ~3 m apart, demonstrating how instruments can bias data. We asked students to assess which of the measurement groups is more precise and/or accurate, using histograms like those in figure 2. Using the entire data set together shows that making more measurements yields a more precise position (green triangle in figure 1). This point is close to (~2 m) the geospatial reference (yellow star in figure 1 and green lines in figure 2). Considering the ~8 m accuracy of the positioning system used by smartphones (Zandbergen 2009), this result is pretty good. This experiment lets students use their own data to explore concepts typically shown in texts with schematic illustrations.

Seismic wave velocity

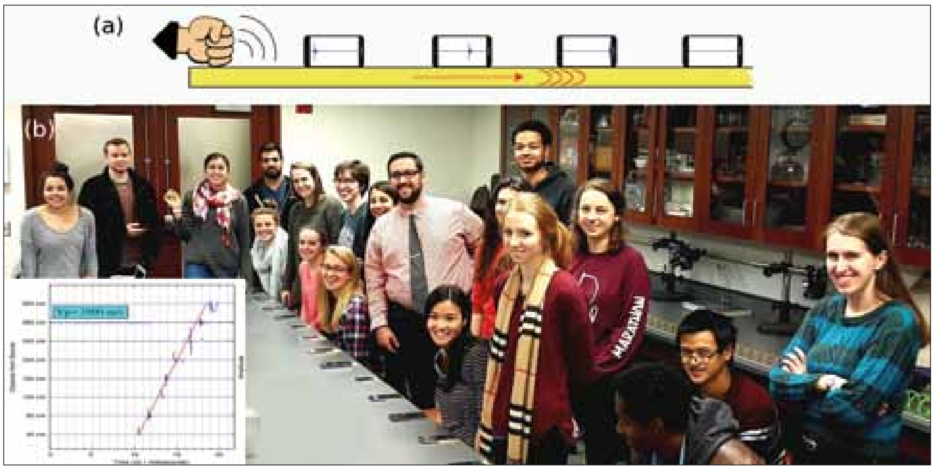
Smartphones can produce and record time-series with their built-in sensors. The signals from the accelerometers in smartphones turn a phone into a small seismometer (e.g. Minson *et al.* 2015, Kong *et al.* 2016, Panizzi 2016). This requires software that



2 Histograms for the east–west (left) and north–south (right) distributions of the position measurements by iPhones (top) and Android phones (bottom). The green lines represent the geospatial reference from Google Earth.



4 A g record from the elevator experiment as it descended four floors. The recording started after the door closed and ended before it opened. A, B and C segments correspond to the lift speeding up, descending at constant speed, and then slowing down.



3 (a) Schematic of the seismic array experiment. (b) The team and a seismic section from the experiment.

pulls the signals from the accelerometer, such as Seismometer 6th, which we used.

In our experiment, we measured the speed of sound (P-waves) in a wooden table using a linear array of phones, analogous to the procedure used in reflection seismology. The students made an approximately 3 m long, evenly spaced, array of phones and used the seismometer apps to record vibration signals generated by pounding on the table at one end (figure 3a). They then extracted the recorded time-series from their phones and uploaded them to a cloud space to share with the whole class. Lab handouts explained how to plot these files while motivating consideration of ideas about *xyz* components of movement, sampling rate and instrument response of the seismometers. Connecting the first arrivals on the records as a section (figure 3b) gave the seismic velocity of the table as ~3500 m s^{-1}, which is about right (Wegst 2006).

An important lesson from this experiment was that different instruments treat the same signal differently, shown by records from closely placed instruments "looking" different. We asked students to explain the reason(s) behind this difference, based on both lectures and lab instructions.

Acceleration of gravity

Students used their smartphones to measure the acceleration of gravity (g) in a moving reference frame. The goal of this activity was for the students to learn how a moving frame can affect their measurements. Originally motivated by Vogt and Kuhn (2012), we followed ideas presented by Kinser (2015) and Sailor (2016). The students used an app to save values of g recorded by the accelerometers in their smartphones as a function of time. A good example of such apps for Android phones is G-Sensor Logger.

First, students calibrated their instruments. Because phone manufacturers usually care about only the relative changes in acceleration, the measurement datum is not always 9.8 m s^{-2}. We had already measured the value of g using other set-ups (pendulum, ball-drop, etc), so students had a good idea of how to interpret their data. To measure g in a moving elevator, students put their phones on the elevator's floor, started recording acceleration as the door closed and stopped before it opened on another floor. Then they plotted the resulting time-series. Figure 4 shows one such plot with the datum adjusted to 9.8 m s^{-2}. Provided with the necessary theoretical background, students were able to mark the three segments in their plots corresponding to the stages of motion as shown in figure 4 and explain their reasoning.

The road ahead

Smartphones let educators develop creative pedagogy in the active learning process (Johnson *et al*. 1998, Buck *et al*. 2013). Such applications can, in some cases, replace computer simulations (White & Turner 2011). However, no educational technology is perfect: phones use different hardware and operating systems (iOS, Android, etc), which results in different processing techniques and variations in the final data. On the one hand, this makes instructors spend time – perhaps not too much – finding workarounds for issues that arise. On the other hand, these differences can be used for educational benefit, as in the accuracy and precision experiment (figures 1 and 2).

Instructors have two options: keep doing labs in the old ways, or benefit now from smartphones as mini-computers and tiny but powerful instruments. These extraordinary devices are only going to become more powerful in time, and our advice is to investigate their potential now. ●

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