# Smartphones and Gravitational Acceleration I: Overview

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# Smartphones and Gravitational Acceleration I: Overview

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Geodesy is a very active and essential research discipline in geophysics but it is not a commonly studied subject at the secondary school or junior post-secondary levels. Far more frequently, gravity and gravitational acceleration are discussed, to some extent, in elementary kinematics or classical mechanics courses. This often takes the form of the force acting on a body or bodies due to gravity, or that the acceleration ($a_{grav}$) of a free-falling body is $9.8(1)\ m/s^2$—which implies the setting of the question is at Earth's surface. While the latter is a reasonable and practical approximation, $a_{grav}$ observed over the surface of Earth varies and is dependent on several factors. These are normally related to elevation and latitude variations caused by Earth's rotation. Earth's rotation contributes negatively to $a_{grav}$ at the equator due to the centrifugal force outward and equatorial bulge, which makes the equatorial radius larger than the polar radius. Offsetting this partially is the positive contribution to $a_{grav}$ at the equator caused by the equatorial bulge because of the extra mass comprising the bulge.

In geophysical exploration, the measurement of gravitational acceleration (here referred to also as simply "gravity") has applications anywhere a physical density contrast exists. It can be used for subsurface detection of dense mineral deposits (e.g., iron, nickel, lead, uranium) or for finding large subsurface cavities.[1-4] In archaeology, gravity has been used to locate underground tunnels used by ancient civilizations.[5] In other applications, gravity has been used to monitor water levels in aquifers[6] or even used to predict volcanic eruptions.[7]

Gravimeters are devices used to measure minute variations in the magnitude of Earth's local gravitational field, caused by a mass (above or below ground level) or cavity that exhibits a sufficient density contrast from the surrounding material.[8]

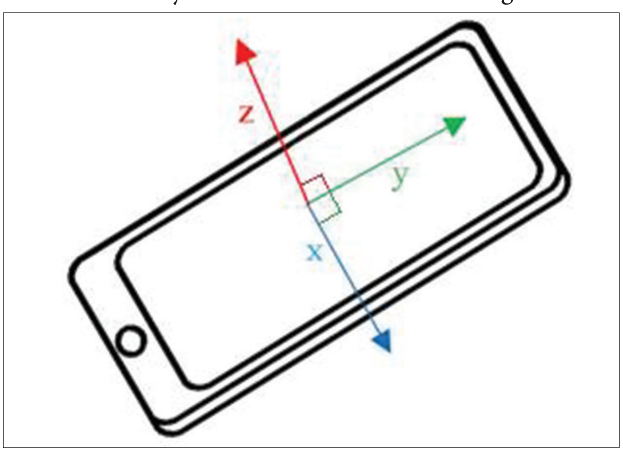


**Fig. 1. Illustration of the positive *x*-, *y*-, and *z*-component axes as used by the GraphicalGW application. The *x*- and *y*- axes are within the plane of the smartphone screen, while the *z*-axis is perpendicular to that plane. For the Physics Toolbox Sensor Suite application, the *z*-component axis is directed in the opposite direction. To help facilitate data analysis, *z*-component measurements/data exported from Physics Toolbox Sensor Suite were multiplied by -1.**

Gravimeters are delicate and sensitive devices that can easily be damaged and can require frequent calibration if not handled properly and with care, which establishes a risk when used by many students in a laboratory hands-on exercise. Depending on the experience of the operator and length of the transect over which a survey is made, measurements taken using a gravimeter can be time consuming for adequate student hands-on participation. The greatest impediment to using an exploration quality device, however, is the large purchase cost of a gravimeter (tens to hundreds of thousands of dollars) and the additional cost to maintain the gravimeter.

Mobile devices such as smartphones and tablets offer an alternative since they contain various sensors intended for built-in features and applications. For instance, the built-in accelerometer, light intensity, and magnetic sensors in mobile devices can be integrated for use as a video game controller or remote kinetic sensor.[9-11] Smartphones are garnering more consideration as useful educational tools in the classroom because of these sensors and the widespread use of smartphones by students. Free applications developed for Android and iOS smartphones are available and have been implemented to assist student learning experience as tools in scientific demonstrations.

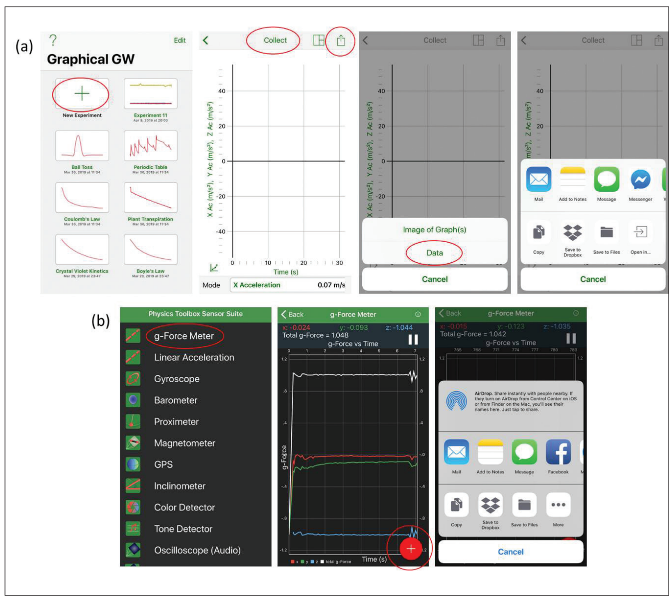


**Fig. 2. Smartphone screenshots showing the procedure for accessing the data measuring interface of the (a) GraphicalGW and (b) Physics Toolbox Sensor Suite applications. The steps go from left to right and the icons to be selected are circled in red. To begin the survey, the "Collect" icon and the "+" icon must be pressed in the GraphicalGW and Physics Toolbox Sensor Suite, respectively. Once completed, the survey data can be exported in CSV format to the student's email address by pressing the "export" icon in the GraphicalGW application. The option to export appears automatically in the Physics Toolbox Sensor Suite application once the survey is completed.**

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## Smartphone applications and accelerometers

The precision of accelerometers in smartphones, which are usually three-axis accelerometers, depends on the conversion of an analog voltage to a digital value. While the resolution of the accelerometer is relevant to the precision of the data, the rapid acquisition frequency of the software applications used to measure accelerometer data is a much more important component for the exercises described in the companion paper, "Part 2: Acceleration Surveys Using a Smartphone with Applications to Gravity and Mechanics."[12] Such applications are capable of detecting and reporting reliable variations in $a_{grav}$ on the order of 0.01–0.001 m/s$^2$, and this is a software-dependent range. Thus, to conduct a successful gravity survey using a smartphone, the detectable variations must be larger than the reliable detection limit of the chosen software application (e.g., larger than 0.01–0.001 m/s$^2$). The scope of detectable effects is discussed in Part 2. As with gravimeters, the acceleration measured by smartphone accelerometers have contributions from all possible sources of forces experienced by the device, not simply the acceleration due to the gravitational force ($F_g$).

Two free accelerometer applications, GraphicalGW and Physics Toolbox Sensor Suite, are compared in the companion paper.[12] The latter has been used in many applications, notably for its unique display of values with resolution of up to 0.001 m/s$^2$.[13-17] As with most applications of this type, GraphicalGW and Physics Toolbox Sensor Suite display real-time simultaneous measurements of the $x$-, $y$-, and $z$-components of acceleration (Fig. 1), as well as the calculated total acceleration, $a_{total}$, from these values using the Pythagorean theorem:

$$a_{\text{total}} = \sqrt{a_x^2 + a_y^2 + a_z^2}, \tag{1}$$

where $a_x$, $a_y$, and $a_z$ are the measured $x$-, $y$-, and $z$-components of the acceleration, respectively. Each measurement of acceleration is accompanied by a record of the time when the measurement was made (i.e., a timestamp). The GraphicalGW application records a value every 0.020 s (sampling frequency of 50 Hz), while the Physics Toolbox Sensor Suite records four values every 0.012 s (sampling frequency of 250 Hz) followed by a gap of 0.076 s. The procedure to access the data using both applications is illustrated in Fig. 2. Data can be exported in CSV file format via email, which can be opened and manipulated using external data management programs such as Microsoft Excel. We note that Physics Toolbox Sensor Suite claims it measures the dimensionless $g$-force, which is defined as the ratio of the normal force ($F_N$) to $F_g$,[18] where the constant value of $F_g$ is 9.80665 m/s$^2$. Consequently, after the data from the Physics Toolbox Sensor Suite have been exported, all components and total values must be multiplied by 9.80665 m/s$^2$ to recover $F_N$. While the software framework of GraphicalGW relies on the $g$-force definition, the conversion to m/s$^2$ is automatically performed by the software itself and requires no additional modifications to the exported data file.

## Final remarks

The newest technology of gravimeters suggests the possibility of transportable quantum gravimeters that can be operated by non-specialists to continuously measure the absolute gravitational acceleration with a precision of μGal,[19] where 1 Gal is equal to 0.01 m/s$^2$. However, as technology advances, more accurate and precise accelerometers will be developed and will eventually replace the current sensors as new smartphones are manufactured. In fact, an accelerometer stable enough to be called a gravimeter, also with a precision of μGal, has been recently developed.[20] These are microelectromechanical systems (MEMS) that are small enough to be contained in smartphones. Such advancements in technology make smartphones more promising and a better investment than gravity surveys carried out for instructional purposes with expensive gravimeters.

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