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Uncertainty analysis

Instructor version

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Uncertainty analysis – Instructor version

Overview of the experiment

- Topic: Mechanics, acceleration, measurement uncertainties
- Target group: Physics and physics teacher training students. Suitable for various phases of studies with varying openness of the experiment, see Possible Modifications at the end of this document.
- Timeframe: 2 hours for the measurements and analysis. 4 hours when including pre-lab exercises and discussions and a short report.
- Requires a group of at least three students.

This is a task which can be used to teach the basic concepts of uncertainty analysis, or as a more open version to give an opportunity to apply and practice skills of uncertainty analysis. The goal is not to get exactly the expected result for gravitational acceleration or in the more open version to even necessarily succeed in answering the research question that the group sets itself, but to rather think about the random and systematic uncertainties present in the measurement, how each measurement apparatus (smartphone) is different, and how one can take this into account in their experimental design and analysis.

The task is rather simple to execute and administer and requires essentially only a group of people with smartphones. The task can be used in several ways to teach aspects of uncertainty analysis either on campus or as a home assignment, and the ideas of the task can easily be adapted for shorter demonstrations as well.

We have used this task in conjunction with group discussions and short exercises involving uncertainty analysis before the experimental task. Instructors can use their preferred material to introduce concepts of random and systematic uncertainties and how to deal with them before giving this experimental task to the students for analyzing real data.

Required equipment

Smartphones (with accelerometer and the app phyphox), and a computer for graphing and analysis.

The measuring app phyphox

The app phyphox is very intuitive and easy to use. In the open version of this experimental task, the choice of measurement tool is left to the student and either the ‘Accelerometer with g’ or ‘Linear accelerometer’ can be used depending on the investigation. For the beginner version, the tool ‘Accelerometer with g’ makes more sense as one can measure g directly.

In the beginner version of this task, one uses also the Accelerometer statistics tool for phyphox, readable via the QR code:

The tool Accelerometer statistics can be given to students also in the advanced version of the task to help them familiarize with the accelerometer measurements and data. The tool measures acceleration in the *z* direction and makes a histogram of the results. It also computes the mean and standard deviation of the collected data. Students can also be asked to use some other graphing tool to create histograms of their data.

Example narrative with comments and suggestions

Part 1: Getting to know the gear

In this part students take data with their smartphones lying flat on the table. To get a fair comparison they could for example note the following:

- Phones are on the same table as close to each other as possible so that they measure the same acceleration.
- The phones have the same orientation when measuring.
- The measurements are started and stopped at least roughly at the same time. Timed run from phyphox helps.

Students could get a graph which looks something like Figure 1.

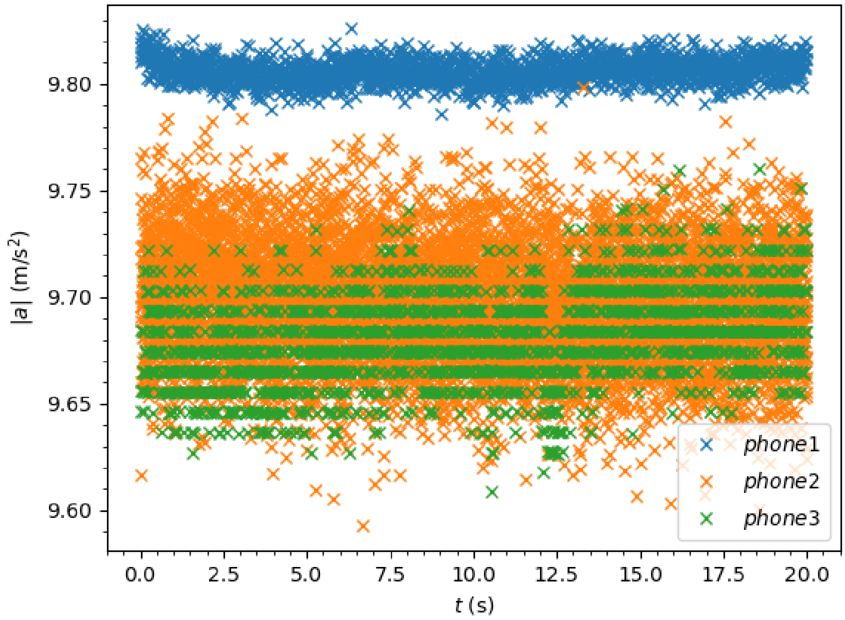

Figure 1: Absolute acceleration measured with three different phones lying flat on a table.

Notes can be made of the spread (standard deviation) of the data in each phone, whether their results agree with each other, and whether there are any systematic effects present. Students should also check whether the orientation of the phone alters the results (which it usually does, see Figure 2 for an example).

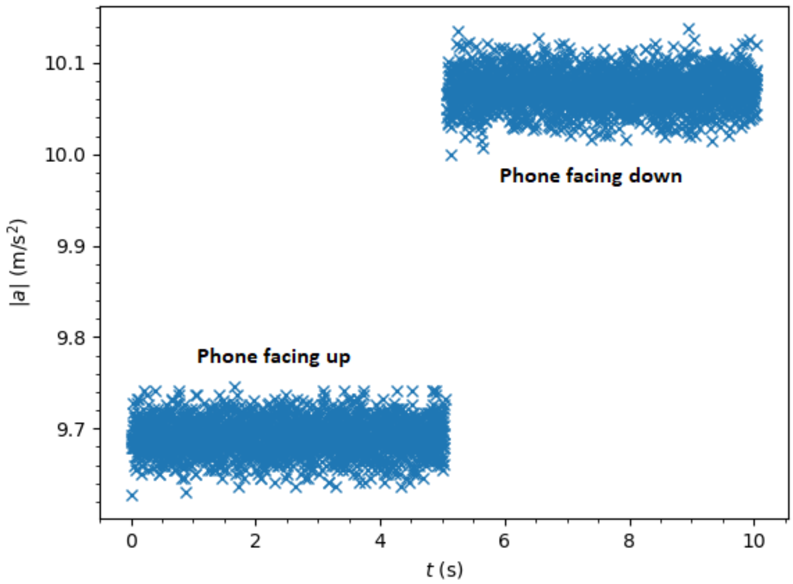

Figure 2: Absolute acceleration measured with a phone facing up and later facing down.

If all of the groups' phones give very similar results, this part of the task can be perceived as not very informative by the students. One can then guide them to think about how they can use that to their advantage in combining the results from each phone when determining their measured quantity in the Experimentation part.

Part 2: Experimentation

Students aiming to measure gravitational acceleration should be encouraged to make measurements beyond the ones made in the first part of the task. What did they learn in the tests of Part 1, and how can they use that information in determining g? Also remind the students about combining data from multiple phones.

Here the idea is not to necessarily obtain exactly the "official correct value of g"™, but rather to measure as precisely as possible with the available instruments. Comparison with some reference value of g has to be made to evaluate the systematic error though.

Possible modifications

- One could use the short investigations in the "Getting to know the gear" part as quick lecture demonstrations or use the figures (like Figure 1 and Figure 2) to discuss aspects of random and systematic uncertainties.
- A more open version of this experimental task can be used in a more advanced laboratory course by replacing the experimentation part (Part 2) with an open inquiry. The assignment could look something like:
    - Make up a simple (simple!) research question which can be answered by a measurement of acceleration. Design and perform an experiment to attempt to find an answer to the research question. The experiment should involve data taken with all of the group's phones. You can measure the same thing with all phones simultaneously, or if you can think of another way of utilizing all phones in the experiment, feel free to do so. Prepare a graphical representation of your data and assess the uncertainty of your results based on your findings in the first part of the task. Does the experimental setup provide any additional systematic or random uncertainties?
    - Could you reduce the uncertainty (statistical or systematic) further? How? Can you think of ways to refine your experiment? Test your ideas if there is time.