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"Developing Digital Physics Laboratory Work for Distance Learning"
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Slamming door

Instructor version

2.3.2022

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Overview of the task

- Topic: Modelling friction effects at a slamming door
- Target group: Physics and physics teacher training students in the study entry phase
- Timeframe: at least 2h, rather 3-4h
- Recommended social form: partner work (2 students per team)

Regarding the preparation

The aim of this experiment is to test different friction models on the movement data of a slamming door determined by means of a smartphone. Due to this focus of the task on data analysis, intensive preparation for the experiment on the part of the learners is imperative. The starting point for the preparation of the content can be the paper published for the experiment. In addition, some technical preparations are required, provided that the necessary software (i.e. *phyphox* and *SciDaVis* or *Origin*) has not already been installed. If *phyphox* and *SciDaVis* or *Origin* are not yet known to the learners, further preparatory tasks for induction are also useful (for suggestions, see instructions for students).

Regarding the set-up and conduction

For the experiment, the accelerometers (with or without acceleration of gravity g) and the gyroscope can be used. The gyroscope generally has less noise than the accelerometers. In addition, it directly delivers the angular velocities, so that there is no need to convert radial accelerations into angular velocities as it is necessary when the accelerometers are used. Measuring the acceleration of gravity has the advantage that a precise alignment of the smartphone is possible based on the real-time measurement data.

The smartphone should be aligned with one of the coordinate axes as orthogonally as possible (for the accelerometers) or parallel to the axis of rotation (for the gyroscope). This maximizes the measured values, which leads to higher precision. Sometimes it is worth comparing the individual coordinate axes, as the sensors measure with different precision in the different directions. The naming and orientation of the coordinate axes depend on the device.

Apart from the measurement with the smartphone, it is only necessary to measure the distance between the axis of rotation and the smartphone sensor when using the acceleration sensors to be able to infer the angular velocity. The parameters of the door, on the other hand, are not required since the fit equations in Assistance (II) are already normalized to the moment of inertia of the door.

The smartphone should be attached to the outside of the door (against the direction of oscillation) so that it does not come off due to inertia. For fastening, double-sided adhesive tape (holds reliable, possibly adhesive residues) or the attachment of a plastic bag with common adhesive tape, in which the smartphone can then be placed, are suitable. When using the gyroscope, the further away the smartphone is positioned from the axis of rotation, the greater the precision of the measurement gets.

Regarding the data transfer to the PC

There are essentially three methods available for data transmission:

1. The remote function of *phyphox* is used. Here, the smartphone data (with appropriate network availability) is transmitted to the computer in real time. A remote start and stop of the recording are also possible.
2. The data is transferred directly to the computer via e-mail, *Bluetooth*, *airdrop*, etc.
3. *Only useful for Android devices*: The data is first stored on the smartphone. Since *phyphox* cannot access the internal memory directly, a file management app such as *TotalCommander* need to be

used, which can receive the file and save it internally. The file can then be transferred e.g. via data cable.

Regarding the data analysis

Before fitting, the data must be prepared accordingly. The following aspects are pointed out:

- The relevant data must be extracted from the data set. For this purpose, the relevant coordinate axis must be determined and only the section describing the closing movement of the door from the impact (see maximum angular velocity) to shortly before the door falls into the lock (see faster decrease in angular velocity, noise) must be used. More information can be found in the paper.
- When using the accelerometers, the angular velocity must be calculated from the radial acceleration a and the distance to the axis of rotation r with $\omega(t) = \sqrt{a/r}$. This formula can only be used for positive acceleration values. Especially at low angular velocities, however, the noise of the accelerometer can become so great that even correct positioning of the smartphone results in negative measured values. These should then either be removed from the record, set to 0 or provided with a different sign.
- The experiment allows an error analysis and calculation to be carried out. In addition to measuring the distance between the accelerometer and the axis of rotation, special attention must be paid to the measurement accuracy of the smartphone sensors. It is recommended to start the measurement a few seconds before the door moves in order to measure the background noise in idle mode. The mean value of these measured values can be identified as a systematic, the standard deviation as a statistical measurement uncertainty.

When using the fit formulas made of assistance II, the following conditions must be observed:

- The fit parameters a, b and c are not directly related to the parameters in $\tau_f = a + b\omega + c\omega^2$, but have already been normalized to the moment of inertia of the door, i.e. divided by this. As a result, the formulas can be used for any door.
- The fit parameter w describes the initial angular velocity. This must also be used as a fit parameter because the algorithm otherwise lacks necessary degrees of freedom.
- The fit equations describe a "drop" in angular velocity due to friction. Therefore, the sign of all measured values must be reversed if the orientation of the smartphone leads to negative measured values (and thus an "increase" in angular velocity).
- The fit equations only apply if the slamming of the door begins at time $x = 0$. Since the measurement is usually started earlier, the time values must be corrected accordingly, i.e. the measurement data must be moved along the x-axis to the left by the corresponding amount.
- The fits depend immanently on the initial guesses, which give the fit algorithm start values (or in *Origin* additionally search intervals). Inappropriate initial guesses can lead to unsuccessful fits. According to the formulas and parameters in the paper (modified by a different door height and mass), positive values less than/equal to $w \approx 0{,}2 \text{ s}^{-2}$ (depending on the force of the door bumping), $w \approx 3 \text{ s}^{-2}$, $a \approx 0{,}29 \text{ Nm}$, $b \approx 1{,}9 \cdot 10^{-5} \frac{\text{Nm}}{\text{s}}$ and $c \approx 0{,}15 \frac{\text{Nm}}{\text{s}^2}$ are expected.

Expected results

As already discussed in the paper, with regard to the two criteria *as large as possible R²* and *fit parameters in a realistic order of magnitude*, the models with Newtonian friction should describe the movement of the slamming door more precisely than models only with Stoke's friction or dry friction. For models with Newtonian friction, the addition of friction terms should increase precision, i.e. DN e.g. is more precise than N and, if necessary, DSN is also more precise than DN. However, this assessment depends very much on the fits (and thus the initial guesses and the algorithms).

Suggestions regarding the assessment

In order to successfully carry out the experiment, intensive preparation of the content is required on the part of the students. To ensure this preparation and to check performance at the same time, an antestat (e.g. in the form of a test, quizzes, ...) is therefore conceivable. Alternatively, the summaries for data evaluation (similar to the keeping of a lab book) created as part of the task processing can also be evaluated. Furthermore, in addition to writing a lab report, a poster presentation is also useful due to the well-discussable data analysis.

Suggestions for modifying the experiment

The slamming door experiment described in the instructions for students allows a variety of modifications and adaptations to individual goals and circumstances. The following is therefore an incomplete list of conceivable variations of the experimental task:

- Sometimes, due to time constraints, the testing of all seven friction models might be not possible. In this case, however, not only the three simple models (D, S, N) should be examined, as the importance of initial guesses for the success of a fit cannot be recognized here. Instead, it is advisable to concentrate on the models with Newtonian friction (N, DN, SN, DSN), since complicated fit formulas are also used here and from a factual point of view the occurrence of Newtonian friction is to be expected anyway. In this case, it is then a matter of identifying the simplest of the four models that describes the data precisely enough.
- Since the focus is on data collection anyway, a predefined data set (second-hand data) can also be output for reasons of time or organizational reasons (e.g. availability of free-swinging doors, number of students) or the data recording can be shifted to the home environment of the students. If the experiment is carried out in presence, the prioritization should be on the data evaluation in presence, as this is in focus of this task and can be better stimulated in presence discussions.
- In addition to the question which friction model most precisely describes the slamming door for a data set (one-time movement of the door), the following questions are also conceivable:
  - What influence does the distance of the smartphone to the axis of rotation have on the significance of the friction models?
  - What influence does the initial angular velocity of the door have on the significance of the friction models?
  - What influence does the choice of sensors (gyroscope, acceleration with/without g) and the choice of axes (x, y, z) have on the significance of the friction models?
  - What influence does the investigated object (e.g. different doors, or windows, etc.) have on the significance of the friction models?

Other remarks

- In fact, the seven friction models discussed in the paper and in this experiment already represent a simplification of the real situation, since an average torque vector is assumed that fictitiously attacks the center of gravity of the door. Strictly speaking, however, the torque changes incrementally depending on the distance to the axis of rotation, since the angular speed of the door on the axis of rotation is zero and becomes maximum at the door fold. In order to take into account the different angular velocities of the individual door areas and the resulting different incremental torques, the friction model includes both Stokes friction (dominates for small angular velocities, suitable for the areas of the door near the axis of rotation) and Newtonian friction (dominates for large angular velocities, suitable for the areas of the door further away from the axis of rotation).
- An error has crept into formulas 7 and 8 on page 32 of the paper. Correct would be:
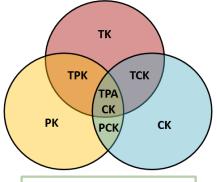
$$\Delta\omega = \sqrt{\left(\frac{\partial\omega}{\partial a_x}\Delta a_x\right)^2 + \left(\frac{\partial\omega}{\partial r}\Delta r\right)^2} = \sqrt{\left(\frac{1}{2\sqrt{ra_x}}\Delta a_x\right)^2 + \left(-\frac{\sqrt{a_{x(t)}}}{2\sqrt[3]{r}}\Delta r\right)^2} = \sqrt{\frac{r^2\Delta a_x^2 + a_x^2\Delta r^2}{4r^3 a_x}}$$

$$= \frac{\sqrt{r^2\Delta a_x^2 + a_x^2\Delta r^2}}{2r\sqrt{r}\sqrt{a_x}} = \frac{\sqrt{r^2\Delta a_x^2 + a_x^2\Delta r^2}}{2r\sqrt{r}\omega\sqrt{r}} = \frac{\sqrt{r^2\Delta a_x^2 + a_x^2\Delta r^2}}{2r^2\omega}$$

- The learning objectives of this experiment for teacher training students can be located in the TPACK-models:

T= technological, P = pedagogical, C = content, K = Knowledge

TK: Digital data collection with & data analyis with *SciDaVis*

TPK: Potentials & limitations of *phyphox*, *Excel* & *SciDaVis* for the data collection and analysis at school

TCK: Using data analysis tools to verify physical models

PK: Potentials & limitations of the reception and replication of an scientific publication for learning physics

CK: Friction models & rotational movement

PCK: Physical complexity of the everyday phenomenon

TK
TPK　TCK
TPA CK
PK　PCK　CK

TPACK: Necessity of using digital data collection and data analysis & acknowleding at least two criteria (R² & order of magnitude) to physically model an everyday phenomenon