Digital Recording and Analysis of Physical Experiments

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Introduction

The main goal of this contribution is to present video recordings and videoanalyses as well as a sound card measurement that might help students to understand physics better. All of the ideas are intended for teachers at schools who can make and analyse their own recordings, not just copy the recorded source material from somewhere.

The digital camcorder or even a digital camera capable of taking a video sequence is a great tool helping us to record and analyze movement, to slow it down, to find significant points (such as the turning point) etc. According to the number of computers among students it is even possible to do an experiment in the class and let the students to analyze it as homework. The experiments are chosen to fit high school level physics or the basic physics course at university level.

Capabilities of the technology

The most straightforward way of doing an analysis of some motion (using a computer) is to record it by a camcorder, capture the video and analyze it in some videoanalysis software. Using this method we are able to get (usually) 25 frames (images) per second (called FPS), having the PAL resolution of 720x576 pixels which is enough for watching even a fast motion, but is not enough for its analysis. Only slower motions can be analyzed with sufficient accuracy. On the other hand, most school experiments may be effectively done using this simple technology.

If we, for any reason, need a higher “sampling frequency” (more images per second), we can deinterlace video footage in a specific way. Each frame captured by a standard camcorder consists of two sets of lines where the even lines were taken one fiftieth of a second earlier than the odd lines. If we divide these sets of lines into two following frames, we get a movie with 50 FPS and half vertical resolution (720 x 288 pixels). For an even higher FPS rate we have to use a special fast camera.

Another approach to the measurement is to use the computer’s soundcard which is in fact an AD converter capable of measuring alternating electrical signal at the rate of (usually) 48 kHz. The layout of such an experiment is different from the layout of a video measurement. An example which will show how it is possible to measure and analyze a mechanical experiment using a soundcard will be described later in the text.

The choice of experiments

We had three criteria how to choose the experiment:

- The video has to bring something new in approach, physics comprehension etc. We didn't want to make things that were done many times ago in just a slightly different way.
- The studied phenomenon must be simple (or simplified) enough to enable making a mathematical model. Otherwise students would just measure some values without any possibility to find out whether the data do correspond with reality.
- The aim has to be reachable with used technology (concerning mostly problems with limited time or image resolution)

The software we used

All of the processes described in this text might be done using only freeware tools. However, the use of more sophisticated commercial programs can make the work more comfortable.

- The videos were captured, cut and exported in the VirtualDub software [1]. The videoanalysis was performed in Viana [2]. There are more videoanalysis tools to be found on the internet, for example DAVID or DiVA and they all should more or less do the work.
- To measure the angles we used CorelDraw Software, but any editor capable of showing cursor coordinates would work. One example for all is the open source bitmap editor GIMP [3].
- Recording and analysis of soundcard signal was done in the Adobe Audition. Once again, all the work can be done using freeware sound recorder/editor like Audacity [4].

Experiment 1 – Falling rod

This is a simple experiment concerning the basics of rigid body mechanics where also the mathematical model can be easily made. Just take a homogeneous rod or tube stand it on one end and let it fall down in a direction perpendicular to the direction of camera view (see Fig. 1).

Figure 1: Falling rod

There are (or at least I found) three main points where to aim interest:

- **Angular velocity of the rod** – the videoanalysis software is capable to give us positions of a selected point of the rod (usually its end) at certain times. Some kinds of the software also exports the velocity, otherwise we have to count it ourselves. On the other hand, this is an exercise that can explain to students how numerical derivatives work.
- The measured velocities can be compared to values predicted by the mathematical model and the correspondence is usually very satisfying.

- **Acceleration of the end of the rod** – the acceleration of the rod's end is higher than gravity acceleration in some part of the motion. This fact might be surprising and it is a good point to let the students think about and explain.
- **The end of the movement** – at the very end of the falling, something strange happens. If we didn't somehow fix the axis of rotation, the rod will start moving forward. On first sight this is in conflict with theory because we all know that if the rod didn't have fixed the axis and there were no friction, it should just fall down and the centre of mass shouldn't move in horizontal direction. In other words, the bottom end rod would slide backwards.
- The explanation is quite simple – the rod didn't slide at the beginning because the axis was fixed by frictional force, therefore the mass centre gained momentum. At the end the friction isn't strong enough to fix the axis any more and the rod starts to move in forward direction.

Points to take care of:

- It is necessary to take into the shot some kind of a "ruler" (e.g. set of marks) to know the scale of the image that is required when making analysis. Because of different standards used in video compression by different algorithms and software, it is better to put two rulers in both vertical and horizontal direction to make sure that the scale is same in both directions. (It is not unusual that pixels in captured clip aren't square but the aspect ratio is 1:1.067 while the analysis software interprets them as squares.)
- Take more shots, not just one, and choose the one where the rod did fall in the direction most perpendicular to the camera view.
- Have plenty of light and use short shutter times, the images will be sharper. For this reason also use the non-interlaced mode, if possible.
- If you do not wish to show the forward movement at the end of the fall, fix the rotation axis with some kind of a hinge.

Experiment 2 – Rolling bodies on a cylinder

Put some kind of round object on top of a cylindrical surface and let it roll down. At some point the object leaves the surface and starts a free fall. The question is where – at which angle or height – the point of leaving lies. Almost every physicist has once solved this problem during his studies, but none has ever seen. We have, and if you take your camera, you and your students can see it too.

This experiment differs from the previous one because it is a good idea to use long shutter times here. If the diameter of the cylinder is small, it is hard to distinguish the point, while if it is big, the movement is too fast for the camcorder. However, we can make use of it: because of long shutter times, we can find one single frame in the clip that contains both movement in contact with the surface and the free fall (Fig. 2). On this single image we can measure whatever interests us.

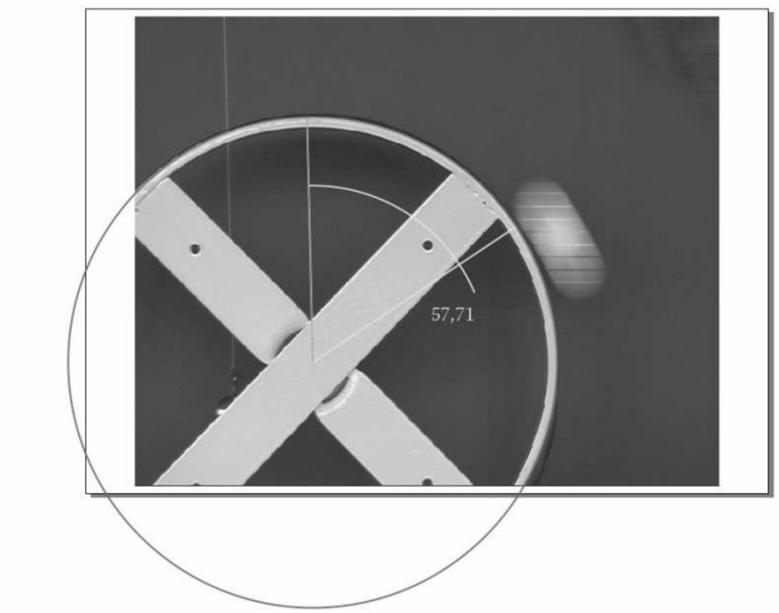

Figure 2: Smaller cylinder at the point of leaving the larger one, angle measurement in CorelDraw

While doing this experiment, we used three rolling objects: a ball, a tube and a full cylinder. When compared to theory, we can see that the measured angle of the leaving point is slightly bigger than its theoretical value in all three cases, and the difference is quite the same for all three objects (see Table 1). This difference may be explained by energy loss due to friction. On the other hand, it is clear that the angle depends on the body's momentum of inertia (a ball of same mass and diameter has lower momentum of inertia than a cylinder or a tube) and the dependence agrees with theory.

	theory	***measured***
ball	54.0°	(57.9 ± 1.1)°
cylinder	55.2°	(58.2 ± 1.4)°
tube	60.0°	(62.7 ± 1.7)°

Table 1: Points of leaving for different bodies

Points to take care of:

- You don't need rulers here because the result is not dependent on scale. You only need to assure that in your image editor the cylinder hasn't an elliptical shape instead of round (once again the problem with non-square pixels as mentioned above might emerge).
- Place your camera as far as possible and use zoom. This ensures that the angle can be easily seen from the crucial image, otherwise the body could be hidden behind the edge of the cylinder and the measured value would be even higher.
- If you like to, draw marks at certain angles directly onto the cylinder. The measurement will be easier, however a bit less accurate.

Experiment 3 – Acceleration on an inclined plane

This experiment uses soundcard instead of camera to study motion. Take a round object (like the ones in previous experiment) with white or at least bright surface and colour half of if with a permanent marker to black. Instead of a microphone plug a phototransistor into the microphone input of the soundcard (this works without any more electrical parts). Now put the body on an inclined plane and let it roll down. Using your hand follow the rolling body with the phototransistor and record the generated signal.

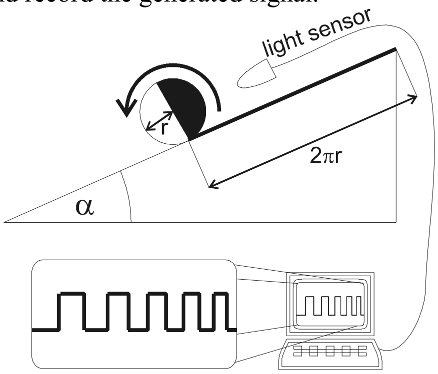

Figure 3: Schematic experiment layout

The phototransistor is open when the bright half of the body is visible to it and closed during the black half. Therefore we get an alternating signal with frequency rising with velocity. Because every switching of colour means that the body has travelled a distance equal to one half of its circumference, we may construct a time-distance dependence graph and fit a parabola into the points. The correlation is very convincing and assures us that the movement has constant acceleration (Fig. 4).

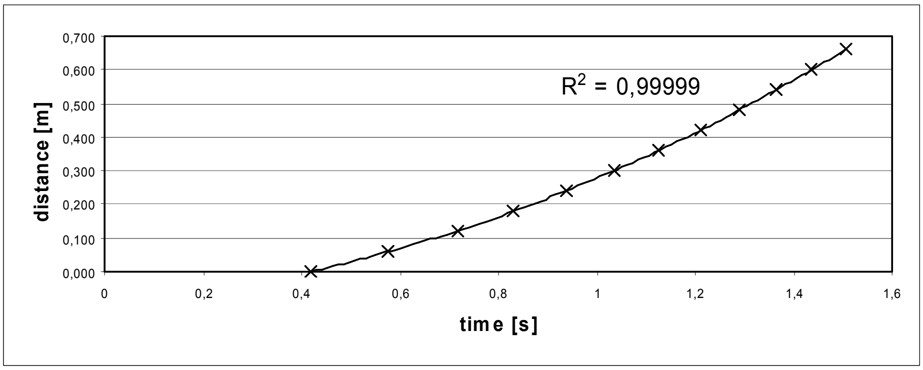

Figure 4: Dependence of travelled distance on time on an inclined plane

As in previous two cases, it is easy to measure the angle of inclination of the board, count a theoretical value of the acceleration and compare it to measured data. Again, the acceleration is slightly lower than the theoretical value due to friction. To prove this, we made a measurement with a ball on a hard plastic board and on cloth (Table 2). The angle was $\alpha = 12.1°$.

theory	$a=1.46\ m.s^{-2}$
plastic board	$a=1.38\ m.s^{-2}$
cloth	$a=1.06\ m.s^{-2}$

Table 2: Measurement of acceleration on different surfaces

Points to take care of:

- The microphone input has to be powered, which is true for most sound cards but not for all of them. We have met a few (laptop) soundcards where there was only one input, same for both link and microphone signal and the connection of phototransistor was more complicated.
- When reading the time from audio software, make sure what the units on the time scale are. These might be as well seconds or CD frames as samples, whereas some of them are "real" time units and some correspond to the sampling frequency.

Conclusion

The aim of this text was to inspire other teachers and show them a possible and available tool (or method) that can be used in physics teaching. Because most of the software tools or their equivalents are downloadable free of charge and also other hardware used (besides camera and computer of course) is very cheap, this might be an interesting complement to the traditional approach to school measurements.

References

[1] VirtualDub: video editing software, http://www.virtualdub.org
[2] Viana: videoanalysis software, http://didaktik.physik.uni-essen.de/viana
[3] GIMP: image manipulation software, http://www.gimp.org
[4] Audacity: sound editing software, http://audacity.sourceforge.net