PAPERS

The world in slow motion: using a high-speed camera in a physics workshop

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The world in slow motion: using a high-speed camera in a physics workshop

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Abstract
We present a physics workshop for college students to investigate various physical phenomena using high-speed cameras. The technical specifications required, the step-by-step instructions, as well as the practical limitations of the workshop, are discussed. This workshop is also intended to be a novel way to promote physics to Generation-Y learners who are attuned to a more visually engaging teaching style.

Introduction

The idea of utilizing video technology in teaching and learning is not novel (see for example [1]). Neither is the use of a high-speed (HS) camera as a research tool to observe physical phenomena which normally occur too fast for the naked eye to observe. In the past, such experiments could only be conducted by well-funded private researchers, in well-equipped research and development laboratories. The recent advances in image capturing and data storage capability, however, have revolutionized cameras. For one thing, a camera is barely considered a luxury item nowadays. For another, the size of a typical camera has been significantly reduced to the size of our palm and so has been dubbed the 'compact camera'. Furthermore, such compact cameras can now serve multiple purposes, from taking snapshots to video recording. Some compact cameras are even equipped with high-speed video-capturing technology, ranging from 5 to 1200 frames per second (fps). Thus, using such a camera to study nature is no longer an activity confined to the realm of well-funded research facilities.

In a bid to promote physics to the younger generation, we designed a couple of experiments involving HS cameras and packaged them into a physics workshop. This workshop was originally designed for first-year college students (15–16 year olds). However, it is not difficult to adjust the difficulty level of the workshop (in terms of the questions asked, the experimental design required, the detail of data analysis, etc) to suit the audience.

In the subsequent sections, we start by describing the technical specifications and the various experiments we conducted in the actual workshop. We will then discuss some potential limitations pertaining to the use of HS cameras

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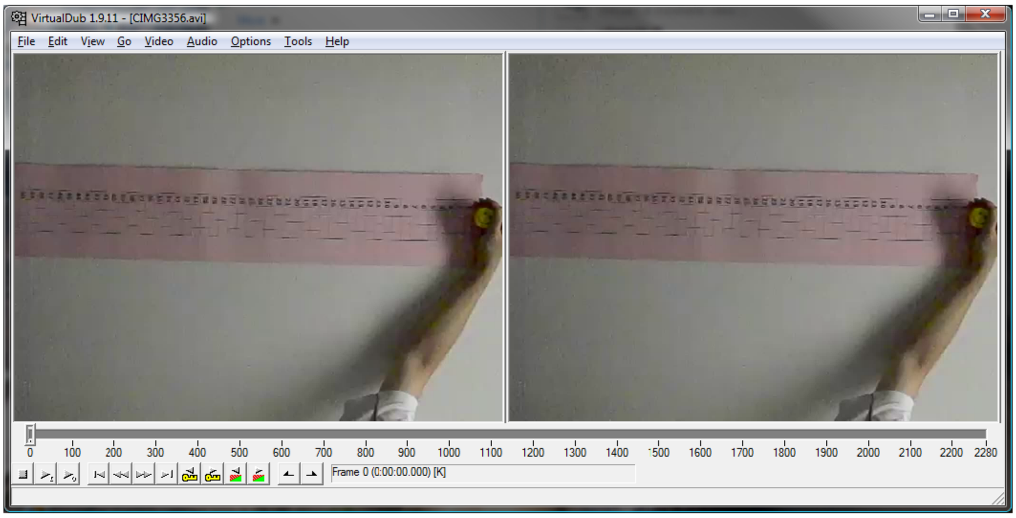

Figure 1. A print-screen shot of Virtual Dub in action. The left pane is used to view the video as a whole, while the right pane can be used to analyse the video on a frame-by-frame basis, using the slidebar and buttons below the panes.

for practical consideration. We finally conclude this paper with some notes on how this workshop can be of relevance to the teaching and learning of Generation-Y students.

Workshop

Technical specifications and software used

The high-speed camera used in this workshop is the Casio Exilim EX-ZR100. Relatively cheap and compact, it is easy to move around in a dynamic workshop environment.

A scale of known length is used in the background. By knowing the recording frame rates of and counting the number of frames for the object to move from one location to another (relative to the scales in the background), one can deduce the distance travelled and the time taken by the object to cover this distance. One can further deduce other kinematic properties, such as the speed and acceleration of the object.

Two different pieces of software, one for image processing and the other for video analysis, are used. A Pazera Video Converter [2] is used to convert the *.MOV format, which is the camera's default video format, to Motion JPEG format for frame-by-frame video analysis using Virtual Dub [3]. These pieces of software are chosen because they are freely distributed for non-commercial use. Besides, they do not require installation; a simple plug and play from a thumb-drive to the host computer will do. It is important to utilize freeware, which everyone has access to, to encourage students to try out their own 'slow-motion' experiments beyond the workshop (see figure 1).

Video analysis can also be performed using the software Tracker [4]. The major benefit of using Tracker over VirtualDub and Pazera is the software's ability to analyse the kinematics of the object automatically using its Autotrack feature. Students, however, have to be reminded to adjust the frame rate (under clip settings) to the value used in the experiments, or else the analysis and graphs produced by the software may not be accurate. Moreover, Tracker requires installation on the host computer. As it is developed and run on a Java programming platform, it also requires the installation of Java 1.6 on the host computer (see figure 2).

Station 1. Yo-yo yeah

Instruction. Ignoring air resistance, any object falls freely at the rate of 9.81 m s^{-2}, which is the earth's gravitational acceleration. A yo-yo, released, will fall and unwind the string that initially is wrapped around it. Compare and discuss the acceleration of the unwinding-falling and the free-falling yo-yo. Will this yo-yo fall at the same acceleration as a freely falling object? What affects its motion? For instance, say, we

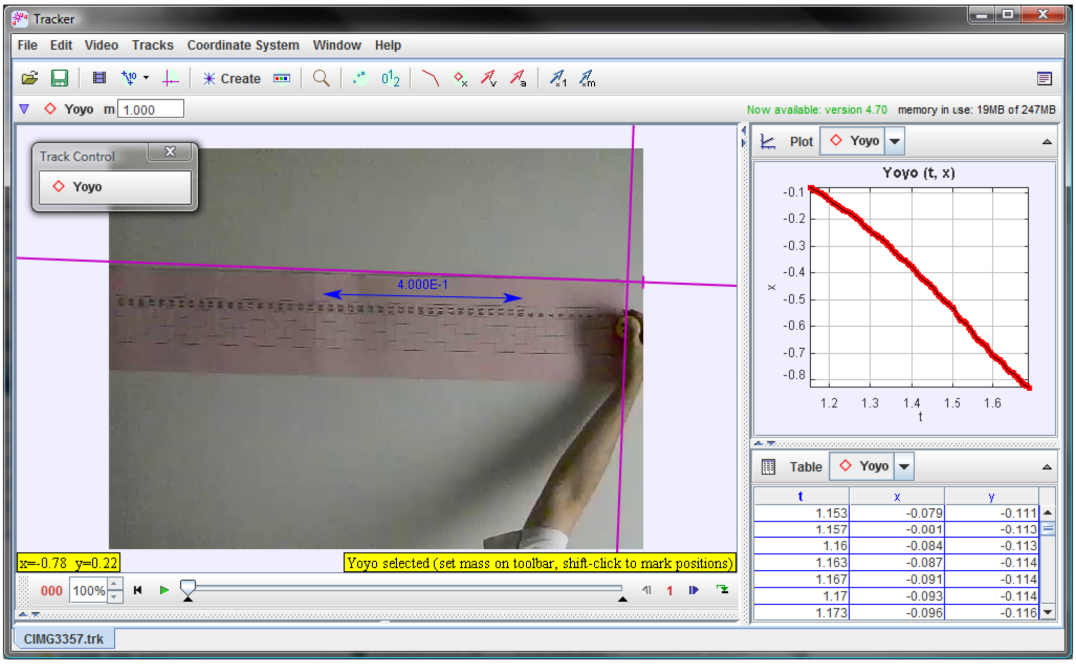

Figure 2. A screen print of Tracker in action. The software is able to analyse and plot the kinematics properties of the system under study (see right column).

vary the mass of the yo-yo, how would it affect the acceleration in the two cases?

Methodology.

(1) Ask one of your teammates to stand at the designated spot, at which the measuring placard is located, as shown.
(2) Set the high-speed camera to a rate of 300 fps.
(3) Ask your teammate to let the yo-yo unwind while recording the whole process.
(4) Copy the video to your thumb-drive and analyse it using the video-processing software.
(5) From the video analysis, determine the acceleration of the unwinding yo-yo.
(6) Repeat steps 3 and 4, but this time letting go of the yo-yo so that it is simply free falling. (See figure 3.)

Station 2. Funky slinky

Instruction. Let us start with a question. You are holding one end of a slinky, while letting the other end freely hanging. If you then let go of the slinky, what do you think will happen? For instance, will the slinky maintain its length while falling, resulting in the bottom-end of the slinky hitting the ground first, followed by the top part a while later? Or will the slinky compress a little bit? Or will it fall in a complicated manner with its centre of mass always falling at gravitational acceleration? We will find out the answer through this experiment.

Methodology.

(1) Ask one of your teammates to stand at the designated spot.
(2) Set the high-speed camera to a rate of 300 fps.
(3) Ask your teammate to release the slinky and keep recording until the slinky hits the ground.
(4) Copy the video to your thumb-drive and analyse it using the video-processing software.

Yo-yo yeah and funky slinky involve topics such as free-fall motion, Newton's second and third laws (in the context of weight, spring force and drawing free-body diagrams) and rotational dynamics (torque, moment of inertia).

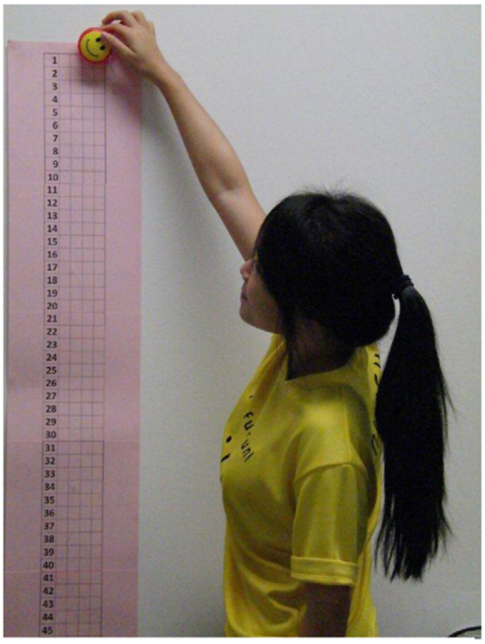

Figure 3. A demonstration of the yo-yo being dropped with a distance marker in the background.

Station 3. Rolling! Rolling down the hill!

Instruction. A solid cylinder (full can) and a hollow cylinder (empty can) are racing down a hill. Soon you will establish the fact that a solid cylinder always takes less time than a hollow cylinder to roll down the incline. What about a partially filled can? Given the fact that a partially filled can is 'somewhere in between a solid and a hollow cylinder, one may think that a partially filled can would reach the finishing line behind the full can, but ahead of the empty can, i.e. 'somewhere in between' the two extreme cases. Is that *really* the case? Let's find out.

Methodology.

(1) You are given cylinders containing liquids of various types and volumes.
(2) Take the cylinder that is completely filled with water (i.e. our 'solid' cylinder). Roll it down the incline plane provided with a measuring tape (see figure 4).
(3) Observe the motion of the cylinder down the inclined plane. Also, record the process using a high-speed camera set at 300 fps.
(4) Copy the video to your thumb-drive and analyse it using the video-processing software.
(5) Repeat steps 1–4 for the remaining cylinders filled with decreasing volumes of water. The last cylinder, which is empty, is essentially just a cylindrical shell.
(6) Plot the graph of time taken to complete the course against the volume of the cylinder.

This experiment involves the concept of rigid-body mechanics.

Station 4. Big splash

Instruction. Collisions between two solid-hard objects are straightforward. A collision between two liquid objects, such as a liquid drop on a liquid surface is much more complex, but is still a common phenomenon, e.g. in waterfalls, fountains, raindrops etc. Scientists have been studying this phenomenon for various industrial applications (can you think of one?) as well as out of pure curiosity.

Methodology. The experimental setup, which involves a retort stand, a couple of clamps, a burette, an adjustable platform, dyed liquid (the 'droplet'), a wine glass full of water (the 'reservoir'), some lighting and (of course) the high-speed camera, is shown in figure 5.

You do not need to follow the setup shown exactly. We will also leave the recording frame rate up to you. Just make sure that you have sufficient lighting and contrast so that you can analyse the frames clearly. Remember that the camera's image quality drops as you increase its frame rate.

A couple of things can be studied from this setup. You can start by varying the distance between burette tips from the surface of the reservoir in order to study how the height difference affects the impact between the two liquids. You will soon notice that as the height increases, the impact produces a higher 'jet', which refers to the water column that spurts up upon impact.

Station 5. Free for all

In this last station there is no theory or instructions. This station is meant for students to design

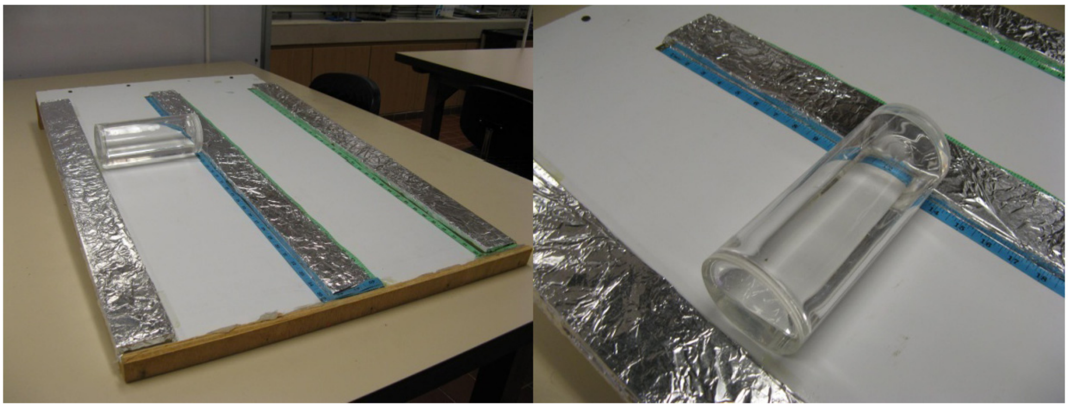

Figure 4. Experimental setup for 'Rolling! Rolling down the hill!'.

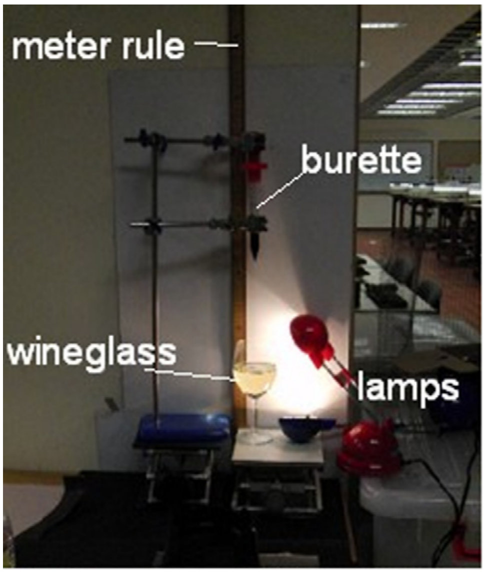

Figure 5. Experimental setup for 'Big splash'.

and develop their own workshop/experiment using items commonly found, based on their own creativity and curiosity, using an HS camera. Imagination is the limit. Some physical phenomena that students normally like to record are bursting water-filled balloons, falling leaflets and high jump in slow motion.

Practical considerations and limitations

We divide students into groups of 8–10. The groups will be rotated through all the first four stations. The last station ('Free for all') is reserved until the end of the workshop, which also serves to give buffer time to engage the students while waiting for the next activity in the itinerary. We allocate 40 min for each station, with a 5 min break for the groups to shuffle between the stations. During these 40 min, students will run and record the experiment, analyse the video, discuss and present the results orally, under the guidance of a group supervisor (normally a postgraduate or a member of the academic staff).

As in the case of other studies using HS cameras, lighting is always one of the major limitations. Lighting conditions determine the image quality captured, which in turn determines the accuracy of the readings. Sunlight is always the best light source, as it provides stable and homogeneous lighting (as compared to, say, neon light, which flickers due to the oscillation of its AC power source). When sunlight is not available (for instance, when the experiments need to be conducted indoor), a filament lamp is recommended.

The image quality is also determined by the recording speed. The Exilim camera used in this experiment, for instance, has three modes of recording speed: 300, 600 and 1200 frames per second. Generally, the image resolution decreases as the speed increases. Besides, due to insufficient exposure, the images recorded at higher frame rates are darker. As far as this workshop is concerned, it is recommended to shoot the video at 300 fps.

Conclusion

Generation-Y is defined as the generation born in the 1980s and 1990s, comprising primarily the children of the baby boomers and typically perceived as increasingly familiar with digital and electronic technology [5]. This generation is also referred to as 'digitally native', in reference to its early exposure and extreme familiarity with any form of technological tools, especially with information technology-related tools [6]. In other words, this is a generation who grew up in the era of 3M, standing for (1) MTV (i.e. arguably the most popular cable TV channel among youngsters), (2) MSN (i.e. popular online chat/forum, in reference to convenient internet access) and (3) microprocessors (in reference to electronic chips, which have been driving the progress in computer technology). As a result, it has been reported in the literature [7, 8] that such exposure has caused a shift in students' learning patterns towards audio–visual cues rather than step-by-step instructions from text. While the trend is varying from one country to another to a certain degree, it indeed describes the typical characteristics of Singaporean students. In fact, Singapore's Ministry of Education is riding on this trend by introducing info-comm technology (ICT) as part of its curriculum masterplan [9].

Physics, on the other hand, is deemed to be one of the most challenging subjects. This workshop has thus been developed to address the need to bring physics down from the realms of abstract and complicated formulae to something practical beyond textbook knowledge. We do not start with equations, rather every instruction starts by explaining phenomena common to everyday life experience, and ends with open-ended questions and challenges for the students to figure out the answer. No doubt a student who pursues physics as a degree (and perhaps as a career) will eventually be required to go through the rigour of analytical thinking and mathematical exercises. However, as far as our target audience is concerned, using HS cameras to study common natural phenomena may help cultivate interest and excitement towards the subject, especially where (in the context of Singapore's education) physics is only introduced as an independent subject in upper secondary school.

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