Simulation of General Physics laboratory exercise

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Abstract. Laboratory exercises are an important part of general Physics teaching, both during the last years of high school and the first year of college education. Due to the need to acquire enough laboratory equipment for all the students, and the widespread access to computers rooms in teaching, we propose the development of computer simulated laboratory exercises. A representative exercise in general Physics is the calculation of the gravity acceleration value, through the free fall motion of a metal ball. Using a model of the real exercise, we have developed an interactive system which allows students to alter the starting height of the ball to obtain different fall times. The simulation was programmed in ActionScript 3, so that it can be freely executed in any operative system; to ensure the accuracy of the calculations, all the input parameters of the simulations were modelled using digital measurement units, and to allow a statistical management of the resulting data, measurement errors are simulated through limited randomization.

1. Introduction

A large amount of the teaching hours of Science curricula are dedicated to laboratory experiments. The advantages of including these exercises are clear since the first contact with Physics at high school; they not only aid the understanding of physics concepts, but also help students learn how to properly handle measurement instruments and process experimental data statistically [1, 2].

Motivated by the costs institutes must face to provide all of their students with the required laboratory equipment, we propose a computerized simulation of some characteristic exercises. Since nowadays computer access in teaching is widespread, the execution of these exercises should come at no additional cost [3–6].

Our intention is not to replace all of the current laboratory exercises with simulated alternatives, since the handling of laboratory equipment and measurement instruments should remain a key aspect in the training of future engineers and scientists. We only mean to convert some exercises to a virtual media, in order to make them accessible to all institutes and to give students access to additional exercises they would not be able to do otherwise.

A characteristic General Physics exercise is the calculation of the numerical value of the acceleration of gravity on the surface of the Earth, using the free fall motion of a steel ball. Taking a real exercise (which can be found at the General Physics laboratory of Universidad de La Laguna) as a model, we generated an interactive diagram from which students can obtain experimental data.

The initial height of the ball can be set manually, and the application returns the corresponding fall time; a limited uniform noise is added to simulate measurement errors, so that data can be processed statistically. In order to increase the appeal of our simulation to young students, we have developed a graphical user interface which emulates the appearance of the real laboratory exercise, rather than just return time data for different height input values.

2. Laboratory exercise
The required equipment for the laboratory exercise, shown in Fig. 1 is:

- A metal base which supports a one-meter long vertical metal bar.
- A contact plate, located at the bottom of the metal bar, and an electromagnet, located at adjustable height at the top, fed by a direct current source.
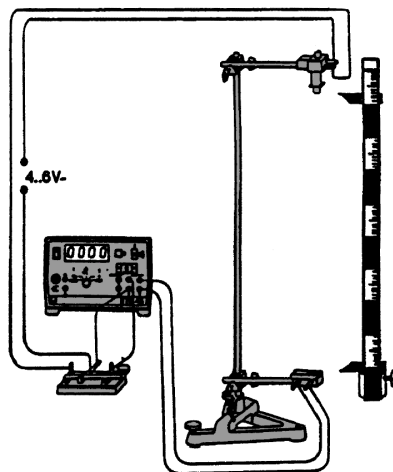- A digital chronometer, and a Morse switch which activates it and deactivates the DC source.

Figure 1. Laboratory equipment required for the exercise.

In this experiment, the steel ball initially hangs motionless from the electromagnet. When the Morse switch is pressed, the current is turned off, the ball falls, and the chronometer starts. When the ball hits the contact plate, the chronometer stops and the fall time in milliseconds is obtained.

The initial height of the ball is named h, and its fall time, t. Considering a free fall motion with negligible air friction, the relation between the travelled space and the fall time is given by $h = \frac{1}{2}gt^2$, where g is the acceleration of gravity. Following this model, the numerical value g can be obtained from the measured values of h and t as

$$g = \frac{2h}{t^2}.$$

At the laboratory, the students set the height of the ball, turns the power source on, and places the ball on the electromagnet. Then, they turn the power off using the Morse switch, which starts the chronometer. When the ball hits the contact plate, the chronometer stops and the students write the fall time down. For each height value h_i, the procedure repeats several times, so as to obtain the mean value of the fall time $\bar{t}_i$, along with its standard deviation. A gravity value can be obtained from these data as

$$g_i = \frac{2h_i}{\bar{t}_i^2}.$$

The student is expected to repeat this process for different height values, in order to obtain a more accurate gravity value: by plotting the values of $2h_i$ versus their corresponding mean time values $\bar{t}_i^2$, the value of g can be obtained as the gradient of the least squares regression line $2h = gt^2$.

3. Simulation

The simulation was programmed in *ActionScript 3.0* [7] and compiled as an *Adobe Flash* [8] file, so that it can be freely executed in most operative systems. The file contains three interactive elements:

- A ball which can be dragged to different heights using the mouse.
- A red button which both starts the execution and resets the system.
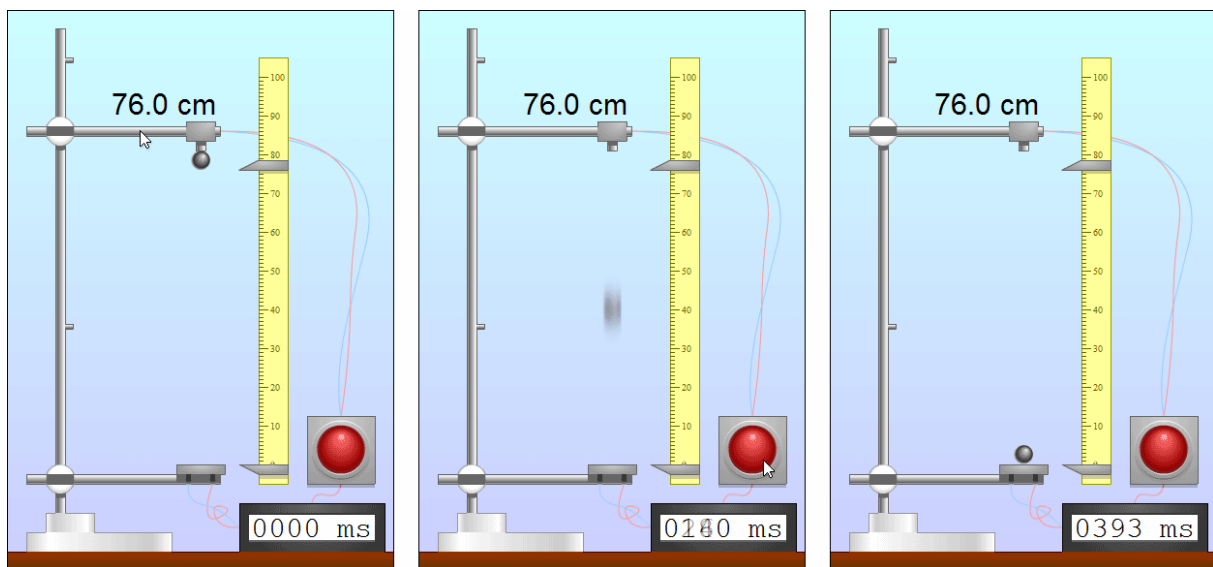- A counter which displays the elapsed time in milliseconds during an execution.

Figure 2. Example of an execution of the simulation.

To create an accurate simulation of the exercise, we required a correspondence between physical and computational scales: the height of the virtual ball can be set between 70 and 310 px (pixels) which correspond to 30 and 90 cm respectively. Therefore, the spatial resolution of our file is

$$\frac{(310 - 70)\ px}{(90 - 30)\ cm} = 4\ \frac{px}{cm};$$

the time resolution of our simulation was set manually to 100 fps (frames per second). Using these two data, the acceleration can be recalculated as

$$g = 9.81\ \frac{m}{s^2} \times \frac{4\ px}{10^{-2}\ m} \times \left(\frac{1\ s}{100\ f}\right)^2 = 0.3924\ \frac{px}{f^2}.$$

When the button is pressed, the time counter starts continually displaying the elapsed time, and the starting position of the ball if saved as y_0. For each following frame t, the height of the ball is recalculated as usual,

$$y_t = y_0 - \tfrac{1}{2}gt^2.$$

The counter stops once y_t equals the lowest position. To simulate measurement inaccuracies, a uniform noise of $\pm 10\ ms$ is added to the final time reading.

To improve the appearance of the simulation, procedural motion blurring and physically accurate bouncing have been added to the motion of the ball. These effects however are merely visual and do not affect the calculations at all. An example of an execution of the simulation is shown in Fig. 2.

Students are expected to follow the same steps as during the real laboratory exercise. They must calculate the mean values and standard deviations of the fall time values, and obtain the value of g as the gradient of a least squares regression line. Fig. 3 shows an example of a plot obtained using the simulation file.
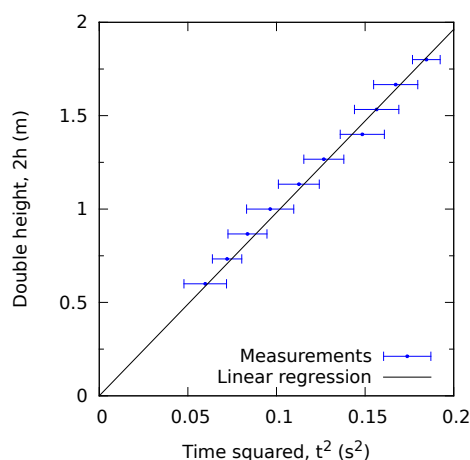

Figure 3. Example of regression line.

4. Conclusion

We have developed a simulation of a General Physics laboratory exercise, at which the value of the acceleration of gravity is calculated from the fall times of a steel ball, initially set at an adjustable height. The exercise has been generated as an *Adobe Flash* file using *ActionScript 3.0* language, so that it can be freely executed under most operative systems. Measurement errors and visual effects have been simulated in order to improve the realism and appearance of the exercise.

This system can be applied to similar laboratory exercises. Future works may include exercises that are too complex to assemble or operate in real life, such as parabolic motions or viscous media which would include a friction factor.

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