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Experiments and data analysis on one-dimensional motion with Raspberry Pi and Python

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Abstract

We propose a project on one-dimensional motion, putting together physics and computer science. An ultrasonic distance sensor is used for getting the position of a selected target along a linear trail, with a Raspberry Pi and a simple Python code. Other simple scripts are proposed for computing velocity and acceleration, as well as for the graphical presentation of the results.

S Supplementary material for this article is available online

1. Introduction

Raspberry Pi offers at low-cost many features of desktop computers and an interface for Input/Output to which different kind of sensors can be connected.

We use an ultrasonic distance sensor, handled through the `gpiozero` Python library. A few lines of code provide the value of the distance between the sensor and a target, along with the corresponding value of time elapsed since a chosen start. So it is possible to graph and to analyze the values of the coordinate x of an object as a function of time, and then to compute the velocity and the acceleration. Several aspects of this experimental activity can stimulate discussion.

2. Setup

Our experimental setup is based on a Raspberry Pi3 model B with Raspbian operating system. The ultrasonic distance sensor is the HC-SR04, which can be powered using the DC +5V output of the Raspberry Pi. Pictures of the setup, codes and further details are reported in the supplementary information (stacks.iop.org/PhysED/55/033006/mmedia). Scripts for data acquisition and analysis are executed from the command shell or using the Thonny Integrated Development Environment.

3. Experiments

As an example we propose the study of the motion of a toy-car on a 2 m track inclined at a certain angle that was measured using a mobile phone and the App Phyphox [1]. First a script, named `ultrasonic_shots.py`, was executed for checking that the ultrasonic sensor was working and that the measured distance had reasonable values. Then the code `distance_recorder.py` was executed for measuring the distance as a function of time. A sleep time of 200 ms was allowed between two subsequent distance measurements. At the end of the incline, the toy-car was stopped by soft packaging stuff. The values measured for an inclination of 11 degrees are shown in figure 1.

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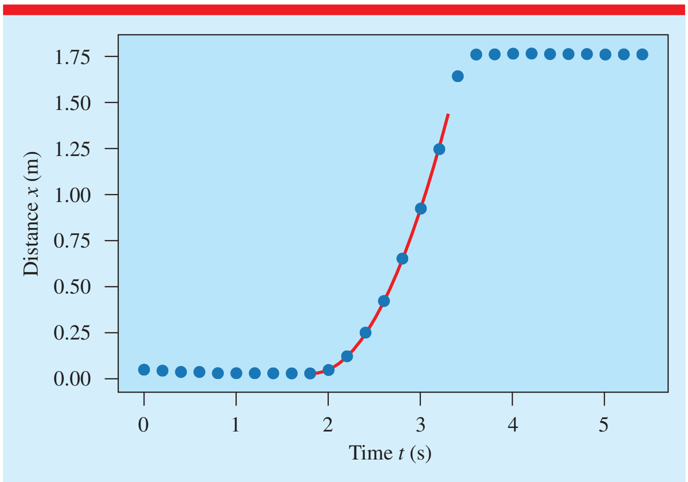

Figure 1. Distance of a toy-car from the ultrasonic sensor along an inclined track versus time. The solid line represents the values computed according to equation (2) with $a = 1.295$ m s^{-2}, $t_0 = 1.829$ s, and $x_0 = 0.029$ m.

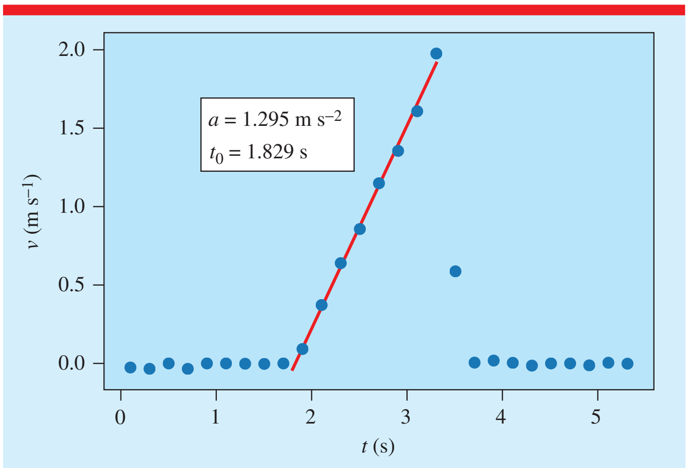

Figure 2. Velocity of the toy-car versus time. The solid straight line is obtained applying a linear regression to the velocity data in a selected time range.

4. Analysis

The average speed in each time interval was calculated by a script exploiting the Numpy library. The results were plotted as in figure 2 using the Matplotlib library [2].

A linear regression was applied to a subset of the velocity data, for times between 1.9 s and 3.3 s, assuming that for a constant acceleration a

$$v = a \cdot (t - t_0). \tag{1}$$

The analysis performed using the script `linear_fit.py`, based on [2], provided $a \simeq 1.3$ m s^{-2}. For comparison, a constant value $a = g \sin\theta$ would be expected for a body sliding on a frictionless incline. For $\theta = 11°$ this would give $a \simeq 1.9$ m s^{-2}, in reasonable agreement with the experimental results, taking into account the effect of the friction forces on the sample motion.

On the other hand, the average acceleration in each time interval available, was evaluated using the velocity values of figure 2. The computed

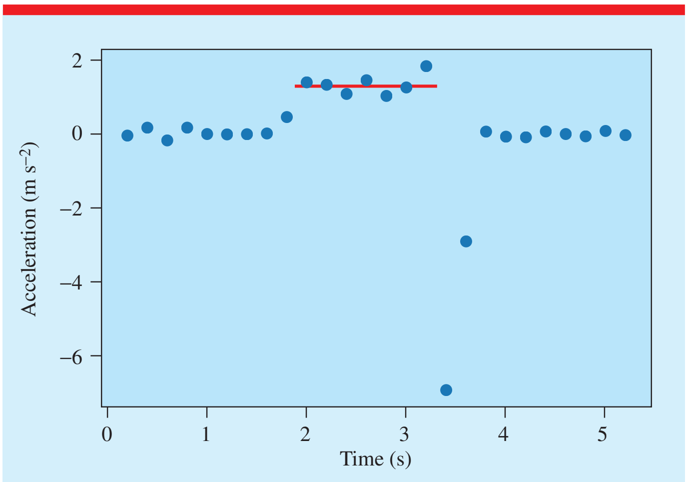

Figure 3. Average acceleration of the toy-car versus time. The horizontal line corresponds to 1.295 m s^{-2}.

values, shown in figure 3, are comparable with the assumption of a constant acceleration in the time range 2–3 s. Moreover, the value of acceleration obtained from the linear fit can be used for modelling the behaviour of x as a function of time,

$$x = x_0 + \frac{1}{2}a(t - t_0)^2 \tag{2}$$

as shown in figure 1.

5. Discussion

This setup could be used for an introductory session on velocity and acceleration for high school students or it could be intended, for instance, as a laboratory activity for undergraduate students in computer science. Different aspects could be highlighted as follows.

RPi Presentation of the Raspberry Pi and assembly. Operating system and pre-installed applications.
GPIO The GPIO interface of Raspberry Pi, providing connection to +5V DC, ground, digital output +3.3 V, digital input.
Sensor The ultrasonic sensor HC-SR04 and how it works. How to: mount the sensor; get the data from the sensor. Verify measured values and measurement range. Choosing a suitable target: a wall, an apple, a toy-car?
Collecting data How to get the data from the sensor as a function of time? What is the suitable rate at which the distance measurements should be acquired?
Analysis How to compute the velocity? Do we observe a constant velocity? Graphical representation of the results. How to estimate the acceleration? Do we observe a constant acceleration?
Further work (Challenges) (a) Writing the code for calculating the velocity, and the acceleration. (b) Making a comparison between the experimental data and the behaviour expected in case of motion with constant acceleration. (c) Using linear regression or non-linear curve fitting to analyze the experimental data. (d) Is it possible to observe the effect of friction? (e) How could the experiment be performed in order to reduce the friction?

6. Conclusions

A setup based on a Raspberry Pi, an ultrasonic distance sensor HC-SR04, and a linear track, provides a cheap portable equipment for educational experiments about the motion in one dimension. The Raspberry Pi can be used for managing the data acquisition, for showing the results, and for analyzing the data. Qualitative and quantitative descriptions of the motion can be formulated, suitable for undergraduate students or for younger learners.

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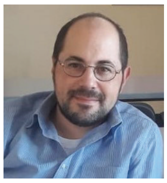

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