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Smartphones on the air track. Examples and difficulties

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**G.RAMA RAO ASSOCIATE PROFESSOR, DEPT. OF PHYSICS, GDMM
COLLEGE OF ENGINEERING AND TECHNOLOGY A.P, INDIA**

**V.MURALI KRISHNA ASSOCIATE PROFESSOR, DEPT.OF PHYSICS, GDMM
COLLEGE OF ENGINEERING AND TECHNOLOGY A.P, INDIA**

Abstract

In this paper we describe a classical experiment with an air track in which smartphones are used as experimental devices to obtain physical data. The proposed experiment allows users to easily observe and measure relationships between physical magnitudes, conservation of momentum in collisions and friction effects on movement by utilizing the users' own mobile devices.

1 Introduction

Smartphones and tablets have sensors that can be used to redesign physics experiments by substituting laboratory equipment with those devices [1]. This technique can enrich data availability in an experiment and also reduces its costs. The work in the laboratory under controlled conditions can also help experimenters to learn the use and limitations of smartphones and to apply them in experiments outside the laboratory. In this paper, we show some results obtained in a classical experiment, pointing out basic concepts that can be explored and analyzed by using smartphones, as well as some difficulties of the work.

II. Using the smartphone in an air-track experiment

A simple and usual mechanics experiment consists in studying linear movement on an air track without friction. On it, positions, speeds and accelerations can be measured by using measuring tapes, chronometers or more sophisticated photoelectric cells. Here, we discuss how smartphones can be used to analyze the movement of a body in three different configurations of the experiment: elastic collisions between two carts, accelerated movement of a cart pulled by a falling body via pulley, and movement of a cart when the air pump is switched off and it is stopped by friction.

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As experimental devices in our work we used two smartphones, a Samsung Galaxy S3 mini and a Samsung Galaxy S4. These smartphones were placed horizontally on the moving carts with their Y-axis pointed along the direction of the movement and their Z-axis vertically. The carts can hold additional weights so that we could study interactions between bodies with same or different masses. To access the data recorded using the sensors of the smartphones, we used two Android apps: Sensor-Mobile [2] and Physics Toolbox [3], so that the advantages or disadvantages, accuracy and numerical noise, of different apps can also be analyzed.

i. Elastic collisions between carts in a horizontal air track

This is a simple experiment that is done by using two carts, each with a smartphone measuring its acceleration, allowing us to check the momentum conservation in a collision between two bodies. In our experiments, we used different configurations

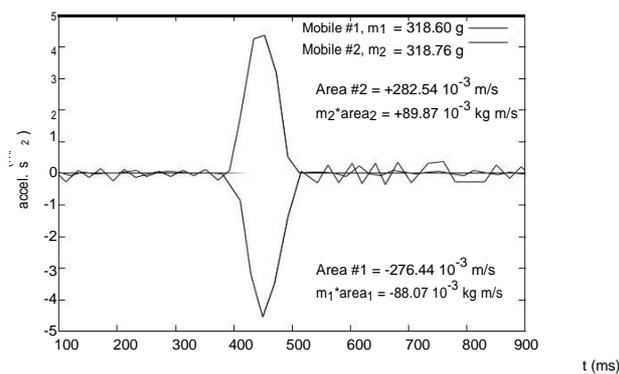


Figure 1: Accelerations of two bodies of equal mass during a collision. A spreadsheet can be useful to calculate the area under the acceleration curves and check momentum conservation readily.

that can be explored: both carts moving on the air track in the same or in opposite directions, or one cart at rest while the other moves towards it. Moreover, by adding different masses to the carts we have analyzed collisions between bodies with the same or with different masses.

Figure 1 shows the results of one of such experiments corresponding to an elastic collision between two bodies (cart plus smartphone) of similar masses. In this case only one of the bodies was moving before the impact. Once the acceleration of each body is measured by the smartphones, the CSV files generated by the apps can be transferred to a computer and analyzed easily using a spreadsheet program. Here the spreadsheet was used to obtain the area under the curve of each acceleration using a simple numerical method like the trapezoidal rule. As can be seen in Fig. 1, when the masses are nearly equal the areas calculated from the smartphone data are also similar (the difference is a little larger than the 2%) considering the experimental noise. And multiplying those areas by the masses of the bodies the conservation of linear momentum is checked, as shown in Fig. 1.

ii. Frictionless movement of a cart pulled by a falling body through pulley

Another dynamics problem studied in the first courses of physics is the movement of a body, on a frictionless horizontal or inclined plane, connected to a cable that passes over a pulley and then is fastened to a falling object. Here, we study such movement by placing a smartphone on the moving cart and measuring its acceleration.

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iii. Movement with friction of a cart pulled by a falling body through pulley

In this section, we show some results that can be obtained if the air pump of the track is set 0 and the cart moves with friction. For this experiment the lower part of the cart should be protected, for example with duct tape, to avoid damaging the air track with scratches, which will also vary the friction coefficient as the experiment is performed. The experiment is the same as in the section ii., except for the existence of friction. The acceleration of the cart is lower than the one without friction, the cart decelerates, and finally stops if the cable is long enough for the falling object to reach the floor

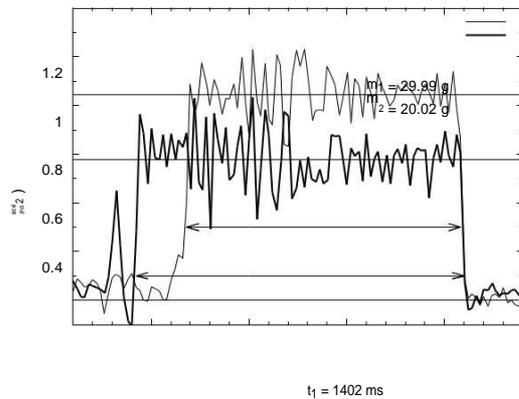


Figure 2: Measurements of the acceleration of a cart on an air track when pulled by different masses in two experiments. The average values of acceleration, in the two experiments, marked with lines in the figure, were $a_1 = 0.84 \text{ m/s}^2$ and $a_2 = 0.58 \text{ m/s}^2$

before the cart gets to the track end.

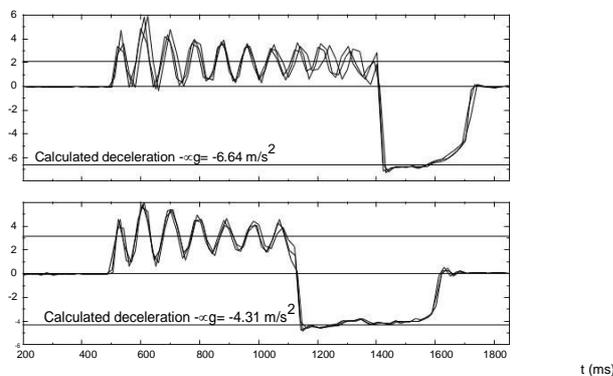
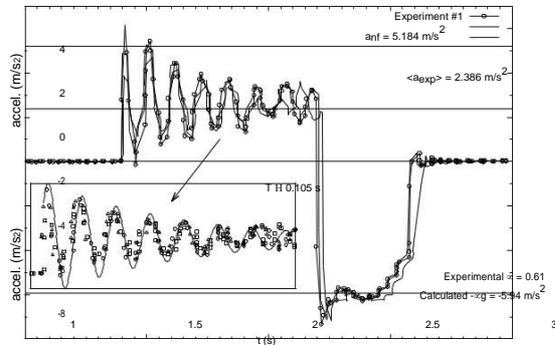


Figure 3: Results of four independent measurements of the acceleration of a cart pulled by a falling body via a pulley when there is friction between the cart and the air track. The values of the theoretical acceleration without friction, a_t , and of the experimental average acceleration, a_e , are marked with straight lines. One of the measurements has been represented with lines and points to show the position of the experimental points.

Figure 4: Accelerations recorded by the smartphone in an experiment like that in Fig. 3 but two different friction coefficients: painted Al cart on Al track (above) and duct tape covered cart on Al track (below). The cart and the falling body masses were $m_c = 317.3$ g and $m_b = 359.1$ g, respectively. The experimental average accelerations of each case have been marked with horizontal lines, as well as the decelerations once the falling body reaches the floor.

but opposite signs. By using a spreadsheet program and the numerical trapezoidal rule, those areas can be easily obtained.

Finally, Fig. 4 shows another result that can be discussed. Results for two different conditions of friction are shown in it: an aluminium cart on an aluminium track and a duct tape covered cart on an aluminium track. Due to different friction coefficients, the cart accelerations are different and, consequently, their travelled times. As for Fig. 3, the users can calculate the dynamic friction coefficients and the corresponding decelerations, and compare them with the experimental results. A final result that can be discussed is the influence of different friction coefficients on the stopping times.

III. Conclusions

Smartphone sensors are very useful tools that permit to do measurements in the laboratory and outside it. The use of these devices can also increase the interest in physics and facilitate the understanding of the physical phenomena. We have shown some results of an air track experiment using a smartphone. Some



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of the concepts reinforced with this experiment are acceleration, collisions, momentum, friction, friction coefficient, impulse-momentum theorem and even elasticity. These experiments can also be useful to learn the importance of sensors accuracy and measuring frequency, as well as the reliability of the used applications.

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