Teaching kinematics and mathematics with a radio-controlled scale car

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ABSTRACT: A project, entitled *Physics and Cars*, was carried out in an attempt to achieve a better level of learner comprehension for physics students regarding the connections between theory and practice. This project took place within the framework of the programme, *Ciência Viva* (Alive Science), which was launched by the Portuguese Ministry of Science and Technology. The main objective of the project was to utilise the higher levels of motivation that resulted from the observation of tests with a 1:10 scale radio-controlled car so as to introduce and derive, in an attractive way, the laws of kinematics and the basics of mathematical numeric derivation and integration. The measuring system and the mathematical methods used in order to calculate the physical variables that characterised the vehicle's motion are described and presented in the article. The tests were performed on a circuit that was normally used for radio-model competition races in order to demonstrate the developed equipment and software.

INTRODUCTION

The main objective of the project, called *Physics and Cars*, described in this article was to gain a better level of comprehension regarding the laws of kinematics by students of engineering and other science and technology courses. A motivating subject was utilised to achieve this, namely a scale model racing car running on a race circuit. The laws and theoretical concepts could thus be introduced in an interesting manner to students [1]. It should be noted that this project was undertaken in the framework of the programme entitled *Ciência Viva* (Alive Science), which was launched by the Portuguese Ministry of Science and Technology [2].

Even if the mathematical support was very simple, students still had the opportunity to acquire an experience-based understanding of the derivation and integration processes, here used for a very well-known real life situation: the numerical calculation of displacement and acceleration using the velocity signal.

MEASURING SYSTEM

A speed measurement device, using an infrared transmitter-receiver, was installed in one of the scale model car's back wheels. The wheel felly has, in its inner side, a circle painted in two semi-circles, one in black and one in white. The beam emitted by the infrared transmitter is thus pulsed by the wheel rotation, resulting in a light signal on the receiver with a frequency proportional to the wheel rotation speed. A radio transmitter sends this frequency signal to a receiver placed in a fixed position, which is close to a computer with a data-acquisition system. Figure 1 illustrates the scheme of the measuring system. Before being acquired by the computer the frequency is transformed into an analogue voltage by means of an electronic circuit designed for this purpose. This was achieved through the analogue to digital converter.
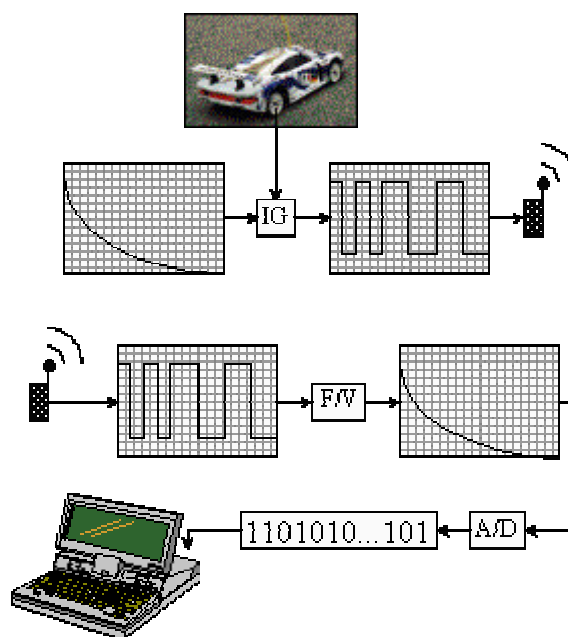

Figure 1: Scheme of the measuring system.

As such, the acquired signal voltage is proportional to the wheel rotation speed and, if there is no sliding between it and the ground, it is also proportional to the linear velocity of the vehicle. Velocity is a vectorial quantity, but the described system is only able to determine its modulus, the scalar velocity, which will be, from now on, referred to only as *velocity* in this article.

Using the described measuring chain (presented in the photograph in Figure 2), which constitutes a one-channel telemetry system, it is possible to visualise, in real-time, the evolution of the physical variables that characterise the car's movements.
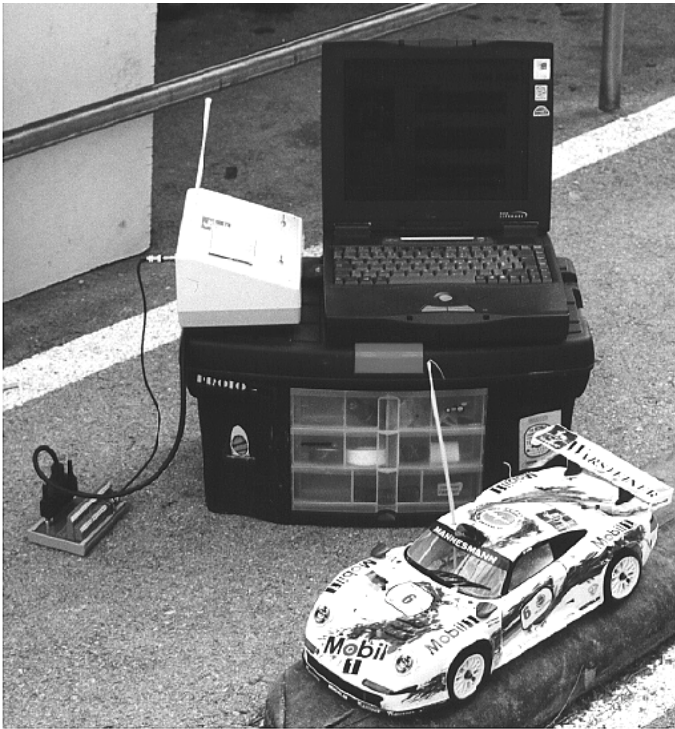
Figure 2: Radio receiver, computer and model car.

A software tool was developed using the *Testpoint* language platform to perform the acquisition, processing and display of data. The graphical aspect of the software interface, after a test

that consisted of going through one lap in a radio-model race circuit, is depicted in Figure 3. It displays some data-entry fields that need to be completed by the user at the beginning, namely: the name of the file to save test data (File button must be pressed), the time interval between the two consecutive samples (dt) and the calibration coefficient of the measuring system. This last item is the relation between the analogue tension acquired by the computer and the rotation speed of the car wheel.

A speedometer appears in the upper left corner of the screen and is scaled in km/h because students have a stronger physical sense of velocity in this unit than in the one used in SI (m/s). An odometer, totalling the linear displacement in metres (m) is placed inside the speedometer window.

Occupying most of the central and right parts of the screen are three graphs, where the evolutions of the velocity, the distance covered and the acceleration are plotted in real time, as a function of time. Inside the windows of the graphs, the instantaneous value of the respective variable is also displayed, being actualised at a pre-defined rate.

In the upper right corner, there are two displays where the mean velocity and total elapsed time values are actualised along the running test. Data files, in ASCII format, containing four columns with time, space, velocity and acceleration points, can be stored at the end of the test, if the user presses the button *Save*.
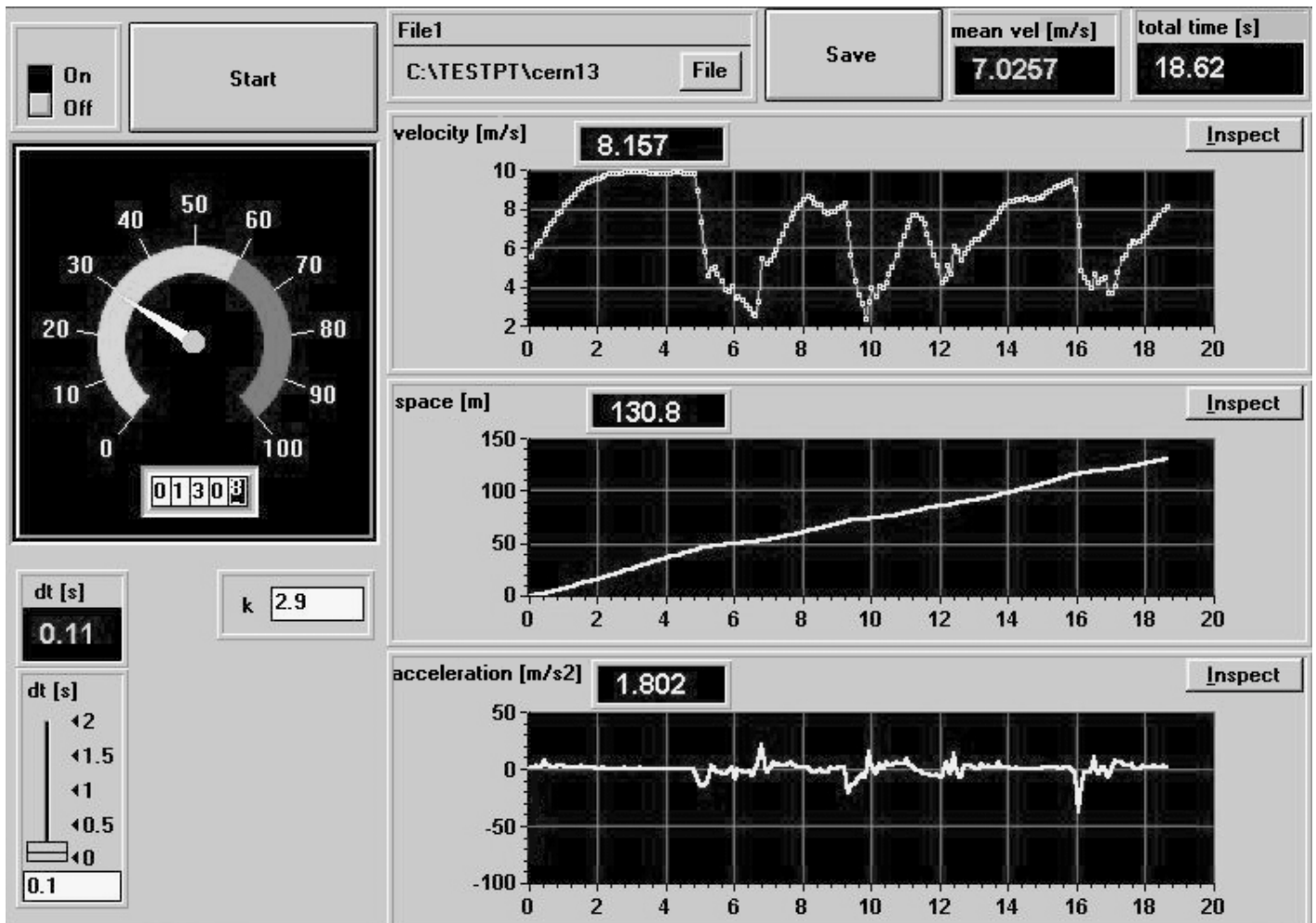

Figure 3: Graphical interface of the data acquisition software.

TESTS

The layout of the circuit used in the tests is presented in the Figure 4, together with the time history of the car velocity signals during two consecutive laps. The curves in the circuit and the correspondent passing moments of the car are marked with capital letters in both graphical representations.
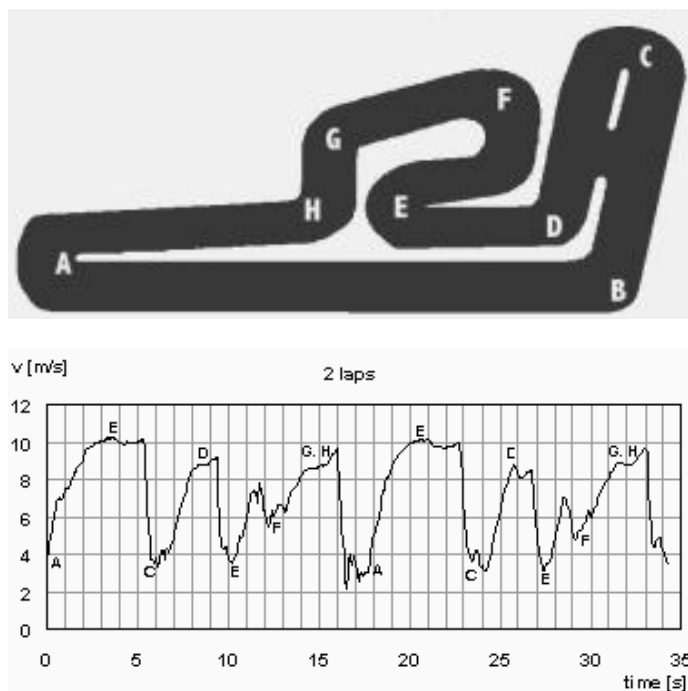

Figure 4: Circuit scheme (top) and time history of the velocity signal during two laps.

The authors can verify that the time per lap was typically 17 seconds, which corresponds to a mean velocity of 7.1 m/s (25.6 km/h or 15.9 miles/h), given that the circuit lap is 126 metres long. The top speed, slightly over 10 m/s, was reached near point B, at the end of the main straight road (stretch).

The space and acceleration signals are calculated from the velocity time series by means of simple numerical integration and numerical derivation methods, respectively. The covered space is computed using the Trapeziums Law. Acceleration can be calculated, in the central point of an interval defined by two consecutive samples, as the quotient between the velocity variation and the time variation.

SIMULATION SOFTWARE

A software program was written in the same language to simulate the time evolution of pure movements (uniform and uniformly accelerated). The same calculation methods, as for the formerly described data acquisition software, were used. The graphical interface is also quite similar (see Figure 5).

The user introduces the parameters relative to the movement (initial velocity, final velocity and acceleration), and, once given the execution order, graphs with the time evolutions of velocity, space and acceleration are plotted. The simulation is performed in such a way that the time for execution of the simulated movement in the software coincides with the time in the real movement. The velocity in each instant is computed, adding to the previous one the variation imposed by the preset acceleration during the elapsed time.

The equations for the movement are derived from the time series generated by the program for velocity, space and acceleration, using linear or polynomial regressions, and based on the least squares method. The differences in the graphical interface, relatively to the former application, are in the lower left part of the screen, where, from top to bottom, are located the following elements:

- The data-entry fields for the initial and final velocity.
- The slider for the introduction of acceleration (positive or negative).
- The three displays for the movement equations.

A good example to be simulated by this software is a car braking trial, as this type of movement corresponds quite closely to a uniformly decelerated one. This is a daily life experience that students can relate to quite easily and, thus, they can easily imagine it, establishing good connections between the theoretical and practical aspects.

Various tests can be simulated, changing, for instances, the initial speed and the deceleration rate. A common car, with brakes working properly and good pavement conditions, has a braking deceleration within the range 6-9 m/s^2. It is possible to show students the growth, with the initial speed, of the spaces for immobilisation or the effect of a pavement with bad adherence, as happens in rainy days. Figure 4 presents the results of the simulation of a braking trial of car at a high speed (180 km/h = 50 m/s).

CONCLUSION

This article described a measuring and data acquisition system, which was developed with the objective of allowing an easy visualisation of the time evolution of the physical parameters that characterise the movement of a small radio-controlled car.

The main objective of this work was the establishment of a good connection between the theory and experimental practice for students. The mathematical and physical concepts were introduced using an interesting and enjoyable approach, thereby trying to improve students' level of interest by what are sometimes considered hard matters.

The experimental set-up can be used for other kinds of tests where other concepts can be experimentally demonstrated. For instance, if the velocity is measured, not in the car, but in a small trailer pulled by it, comparative studies can be undertaken that focus on the measurement of rolling resistance and braking efficiency for different road surfaces.

ACKNOWLEDGEMENT

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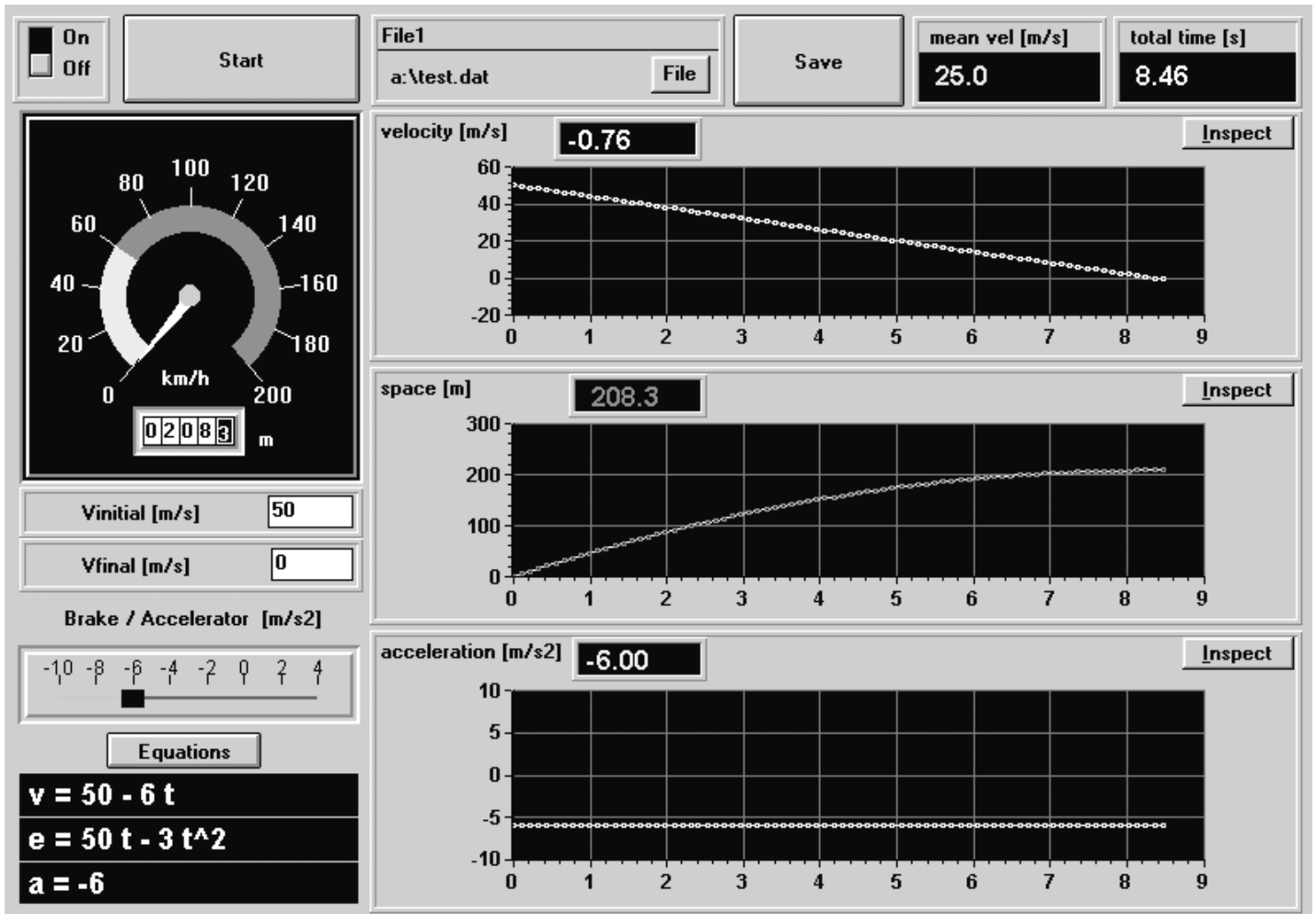2. Silva, M.C.G., Duas voltas à Pista no carro Ciência Viva. *Gazeta da Física*, 24, **2**, 8-15 (2001) (in Portuguese).

Figure 5: Interface of the movement simulation software.