2.6 Data Logger

2.6.1 Introduction

When the main objective of a project-based activity is to discover or verify a general law that controls a phenomenon, or to make some statistics on the experiment, one usually needs to collect lots of data from the real world. The manual acquisition of experimental data, though interesting from an educational point of view, is subjected to unavoidable inaccuracies that can compromise the subsequent analysis. Even when acquiring data from the environment was not initially thought as necessary, this need may arise successively, when, for example, the behaviour of the robot does not adhere perfectly to what is expected, when any aspect of the environment is worth being more deeply and quantitatively analyzed and when it is interesting to study the time profile of a motion in detail.

The Lego Mindstorms NXT firmware permits us to use sensors not only for robot controlling purposes, but, also, to get samples from such inputs and to store them onto an internal file that can be subsequently uploaded on a PC for post-elaborations. The integration of data analysis in a project is a substantial way to organize the development of its stages, particularly during the investigation stage. To describe this feature through a simple but effective example, we prepared an experiment that we called ‘data logger’ (DL). In this experiment the goal is to study the uniformly accelerated motion and to deduce from the acquired data its fundamental quadratic law between space and time.

2.6.2 Building instructions

Because, as we have seen, the NXT servo-motors are speed-controlled devices, it is much simpler to use the natural gravity acceleration in order to impose a constant acceleration to a vehicle instead of forcing a linear increasing profile to its speed that would mean to increase correspondingly the applied power during the motion. Therefore, we built a very simple car on four free-to-rotate wheels without motors (fig. 2.6.1); the car is equipped with a sonar sensor to get space data. Left to move freely on a slope with a constant inclination θ (fig. 2.6.2), the car is subjected to an acceleration, which is the component of the g gravity acceleration parallel to the slope, whose absolute constant value is $g \sin \theta$ (whereas the orthogonal component $g \cos \theta$ is compensated by the static reaction of the plane).

2.6.3 Programming the data logging

The data acquisition regards the distance measured by the sonar sensor in respect of a fixed obstacle put on the starting side of the slope. Starting the acquisition before leaving the vehicle free to move down the slope under the influence of the constant acceleration lets the program store in a file the entire sequence of sampled values of the increasing distance during the motion. In order to analyze the motion, the teacher/student must reconstruct the relation between this sequence of samples and the time. To reduce the influence of the unavoidable delays introduced by the execution of the command blocks in the program, we suggest storing each sample value together with its sampling time with immediately successive commands.

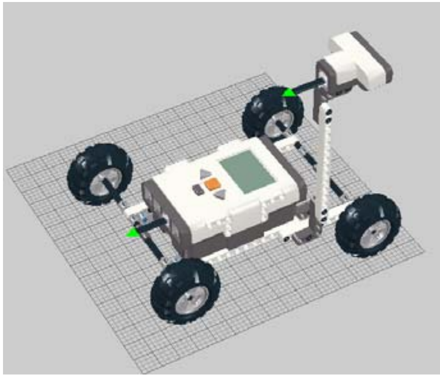

Fig. 2.6.1 *– The simple car*

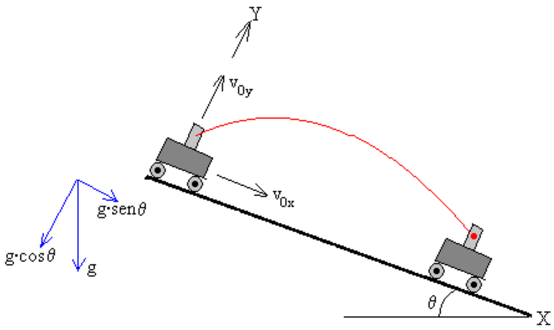

Fig. 2.6.2 *– The slope and the acceleration*

The NXT-G code of the program is shown in fig. 2.6.3 and corresponds to the following NXT-GTD description:

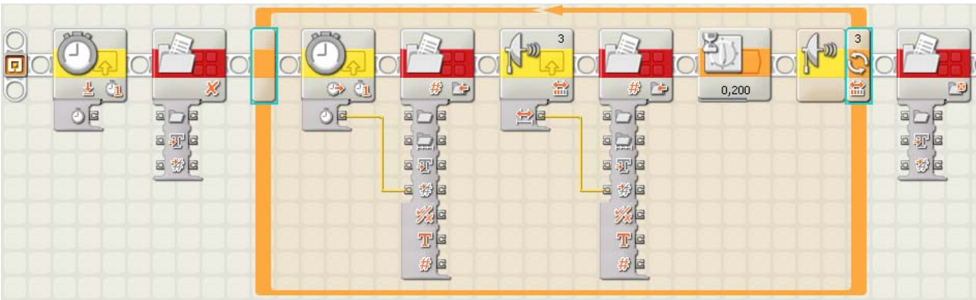

Fig. 2.6.3 – *The Data Logger NXT-G program*

Timer(Num=1, Act=RESET, Cmp=??)

File(Act=DL, Name=dldata)

Lo1: Loop(Ctrl=SENSOR, Sensor=SONAR, Dis=OFF, Port=3, Until=GT 110, Show=CM) [

Ti1: Timer(Num=1, Act=READ, Cmp=??)

F2: File(Act=WR, Name=dldata, Type=NUM, Val=Ti1.Val)

```
 So1:   SonarSens(Port=3, Cmp=??, Show=CM)
 F1:    File(Act=WR, Name=dldata, Type=NUM, Val=So1.Dist)
        Wait(Ctrl=TIME, Until=0.2)  -- wait for next sample time
Lo1]
File(Act=CL, Name=dldata)
```

The first block resets the timer, whereas the second block deletes the file possibly produced in a previous session, to avoid new data being appended to the old ones. In the loop, the program with a period of (about) 0.2 s, samples the measure given by the sonar sensor and writes the value of the timer and the sample in the file. The two readings, that of the timer and that of the sensor, must be done with the minimum possible time separation. The loop ends when the distance reaches a maximum (the end of the straight path of the car) and the last block of the program closes the file. The recorded ASCII file with the acquired data can be uploaded onto the PC with the use of a specific NXT-G function (fig. 2.6.4). Time samples are given in millisecond unit, distances in centimetres.

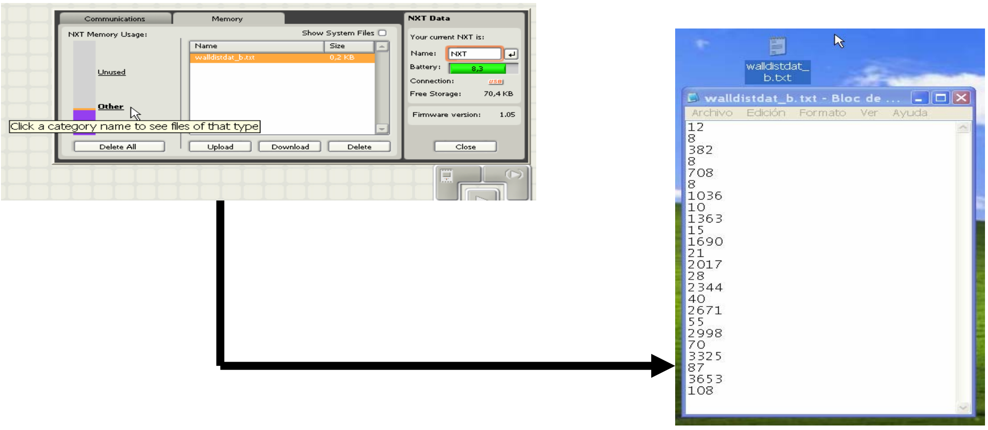

Fig. 2.6.4 – *How to upload the data file*

The acquired data can be more effectively analyzed if reported in a spreadsheet and then plotted: in fig. 2.6.5 you can see the sequences of samples for 6 different repetitions of the experiment. The samples, connected by means of interpolation curves, are shown in the plotting (fig. 2.6.6) together with a fitting quadratic function $f(t)=s_0+v_0*t+a*t^2/2$ with a the assumed constant acceleration, and s_0 and v_0 chosen to make good enough the approximation with respect to the sequence of samples calculated as the average of the 6 corresponding measured samples. One of the most interesting findings that students should “discover” is that a physical phenomenon is only partially perfectly repeatable, due to noise errors and other physical inaccuracies (e.g. irregular friction, limited sensor precision, etc.). The plotting of the results of the repetition of the DL experiment can convince them, particularly when compared with the theory (fig. 2.6.7).

The Slope

Set only alpha(degrees) as the angle of the slope, s0 and v0 for the fitting curve

Alpha (degs)	Alpha (rads)	Accel.	s0	v0
5	0,044	42,8	5,5	11

	Measuring distance to a wall in cm						fitting curve=s0+v0*t+acc*t*t/2		
Time	sample1	sample2	sample3	sample4	sample5	sample6	average	fitting	error (%)
0	6	6	5	5	6	5	5,50	5,50	0,00
0,2	10	11	8	6	11	8	9,00	8,56	5,19
0,4	16	17	13	10	16	13	14,17	13,32	6,33
0,6	23	24	20	16	23	20	21,00	19,80	6,05
0,8	31	32	26	23	31	27	28,33	27,99	1,22
1	42	41	34	30	41	37	37,50	37,90	1,04
1,2	52	53	45	39	53	46	48,00	49,51	3,05
1,4	66	67	57	51	67	60	61,33	62,83	2,39
1,6	80	82	72	65	82	74	75,83	77,87	2,62
1,8	96	98	88	80	98	90	91,67	94,62	3,12
							average error(%)		3,10

***Fig. 2.6.5** – Experimental data on a spreadsheet*

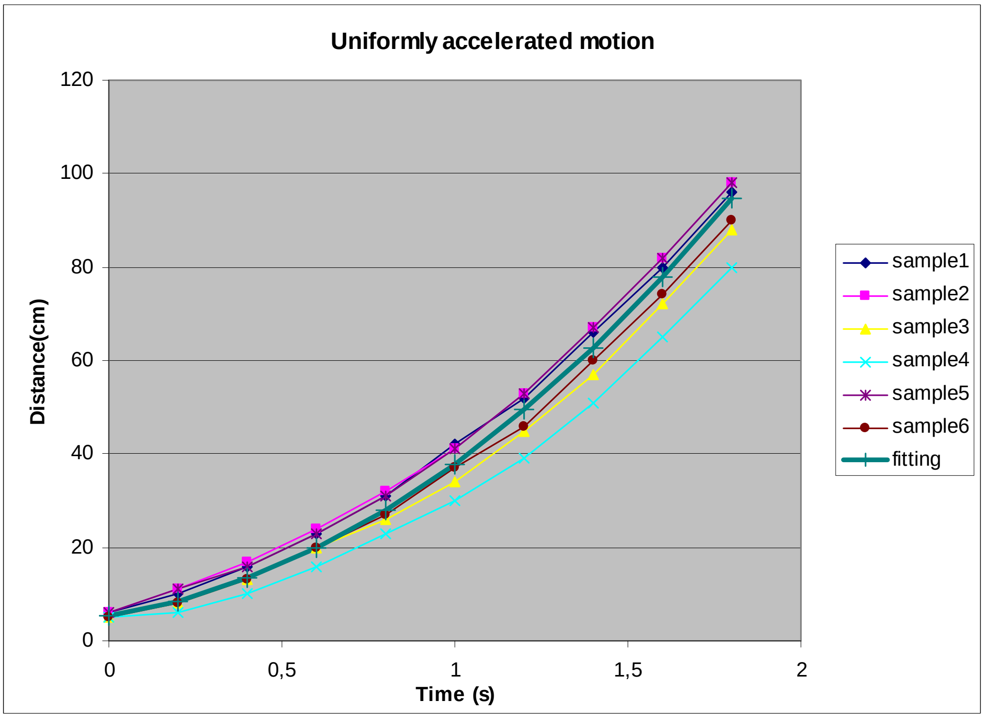

***Fig. 2.6.6** – The DL data plotting*

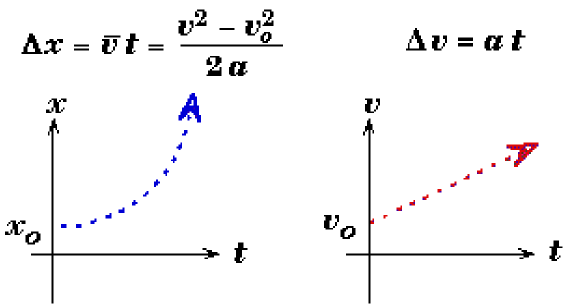

Fig. 2.6.7 – *The uniformly accelerated motion theory*

The accuracy of the acquisition could be improved by storing the sampling time and the associated sample value into two variables before copying them into the file in order to reduce the time separation of the two readings. Another possibility is to correct the stored sampling time of an amount calculated from an estimation of the delays introduced by the execution of the program blocks.

A variant of the presented DL experiment could use a rotational sensor instead of the sonar to provide the measure of the travelled space. In this case, you should use an external rotational sensor (not provided in the standard kit, for instance the old RCX sensor) because, if you connect the wheel to a NXT motor, the motor offers a great resistance when it is not executing a motion command, and therefore it does not leave the wheel free. Moreover, the student would be asked to deduce the linear space from the angle performed by the wheel.

2.6.4 Didactical Issues

After the experiment, the acquired data can be suitably displayed and used for a discussion among the students and the teacher:

- to discuss the evidence of the data in respect of the expected behaviour, trying to find reasonable justifications for possible deviations;
- to deduce laws, constraints, proofs and intuitions from the shared analysis;
- to acquire a deeper insight in the physical phenomenon under experimentation;
- to provide a new awareness, which is the basic condition whereupon new knowledge can be built with a constructivist teaching/learning approach.

The DL example can be used as a prototype to realize attractive, rather complex data acquisition experiments with one sensor and also with more than one sensor. In the latter case the reading of samples might be done as much synchronously as possible to permit correct correlations among the different sensor data. For instance, one could study the correspondence between the rotation of a motor, measured through its internal sensor and the motion of the whole vehicle, measured with the sonar in case of a linear motion, like in the DL example, or with a gyroscope or a compass sensor in case of a rotational motion.