MotionLab

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Abstract— **MotionLab is an experimental system for the study of physical motion created as a learning objective of the Industrial Engineering students. MotionLab uses the accelerometers and the infrared camera of a game controller as a data acquisition interface present in the consumer electronics market. The aim of this system is to monitor and to study the results of physical experiments about solids motion under different conditions. This research line, aimed primarily at education, tries to build low-cost experimentation systems replacing the classic ones, which result, mostly, as less efficient and need more expensive laboratories.**

Keywords-Laboratory experiences; remote laboratories; accelerometer; low cost; motion; sensor, physical experiments.

I. Introduction

Currently, consumer electronics offers better performance features every day, thanks to its large-scale manufacturing, which has produced a decrease in costs. Two of the technology sectors in which faster evolutions have been made are the telecommunications and entertainment sectors in which new products incorporate advanced technologies that traditionally had a high cost.

All over the world the process of technological change resulting from the Information and Communication Technologies (ICT) is causing significant changes in areas like economy, society, science and education, which substantially influence the patterns of production, organization and development.

Two factors have enabled this fact, using ICT as tools of development:

i) Lowering the costs of technological devices (laptops for under 200 €, better and cheaper communication, etc.)

ii) The emergence of new devices equipped with different sensors that allow the capture of environmental information (such as smart phones, game consoles like Wii, equipped with accelerometers, proximity sensors, video cameras, etc.) at lower prices every day.

Nowadays there is a great activity on this field which is called to represent a cornerstone of worldwide engineering education. The recent popularity of the remote laboratories concept and the existence of abundant bibliography prove its importance in the education area. These activities are focused on research areas like [1], which is oriented to microelectronic device characterization, or on learning and educational methods oriented, such as [2], [3] and [4].

One line of the research of the authors is the research of new low cost learning methods in education through remote labs and the simulation of physical experiences for students of Industrial Engineering. Some of the research lines about a low cost laboratory can be seen in [5].

For engineering students, laboratory and practices constitute a fundamental step in the learning process. Indeed, laboratory experiments help them to improve the understanding of concepts and skills, to familiarize with the use and management of measuring equipment and to develop specific skills required for future work. For these reasons, the most important institutions, which deal with scientific-technological training, try to dedicate a large budget to equipment and maintenance practices' laboratories. However, the evolution of technology quickly results in these equipments becoming obsolete and needing replacement, consequently increasing the investment in this educational activity.

With the emergence of the last generation entertainment systems, focusing on getting a great user experience, researchers and professionals that come from other different areas and which are motivated by this reduction in costs and by the easy reuse of components have began to consider these technologies for very different purposes from those that were originally conceived.

In this case, this research line is focused on the reuse of low-cost devices used in the new generation of video consoles, which incorporate technologically advanced control devices. These controls contain different types of sensors such as accelerometers, infrared cameras, gyroscopes, etc. The reuse of these devices has allowed the construction of MotionLab, a high precision experimental system oriented to the study of physical experiments, such as motion experiments.

Consumer electronic devices, that incorporate accelerometers, which can be used for different applications of those they were originally conceived, as it is the case of the Wii remote controller (called Wiimote) connected to other devices with greater capacity to process such as a PC, can be found in the market. In the educational field there are other researches using this remote controller like [6].

The study of physical motion, such as kinetic motion, is essential for engineering students. Students begin to explore concepts such as velocity and acceleration. For a correct understanding, in addition to the theoretical knowledge of these concepts, experimental study is essential for their comprehension as well as practical experimentation. One of the best ways to study acceleration and its effects is using accelerometers to accurately show the characteristics of a concrete experiment. In this laboratory it is shown that it isn't necessary to use high accuracy sensors, and therefore high cost, but low-cost sensors that can perform these experiments and that allow to students acquire a high grade of assimilation of the theory.

In particular an experiment has been built consisting on the study of the movement of a mobile object in an incline plane.

As it will be described later, this is an ongoing project in which the first prototype has just been completed and although it has been tested in laboratory, it hasn't been used by students yet. The first tests will be done in this course (2009-10).

The structure of the paper is as follows. In section II, the system concept is reviewed. In Section III, one experiment as a concrete use case is described. Section IV shows the advantages of the system. Section V explains the experimental results. Finally, section VI draws some conclusions.

II. Description

A low cost laboratory is not just a set of applications that captures several physical data, but must meet certain requirements.

First, students must have in the same application a manual with the theoretical foundations, operating principles and objectives clearly and accurately expressed (operating manual, practice script, etc.).

So all the experiments that have been developed in this laboratory are not limited to programming and assembling of a device, (hardware and software), but require a careful design where certain educational requirements, besides the technical requirements, are taken into account.

User experience is another key factor and therefore the application should be handled easily, with an intuitive user interface. Students should focus mainly on the experiment design and the application has to let them do it.

In addition, it is really important to test the application, under conditions of normal use, with a sufficient number of subjects, and to make an evaluation of the results and to change everything which needs to be changed. Obviously the implementation of this process requires a multidisciplinary team consisting of software developers and teachers of the subject concerned.

The main objective and the origin of this system was to obtain a low-cost universal platform for studying the motion of solids in different conditions. As mentioned, MotionLab is a system for the study of kinetic experiments that allows the study of solids motion in different conditions (collisions, pendulum-like motion, etc.). As a fundamental element, the system uses the Wii remote control device (manufactured by Nintendo and available on the Wii console) and the built-in sensors. It is a flexible and scalable system that enables rapid incorporation of new types of experiments.

A remarkable effort has been made in the MotionLab design making an open and extensible development which enables its expansion and the incorporation of new sensors in the most simple and transparent way.

A web application complements MotionLab which allows students to share and to store the results of the experiments. It also allows teachers or administrators to manage the system.

A. Architecture

Different approaches [7] can be used in order to design the architecture of the system. Two approximations have been chosen, the first one a low-level controller, which is in charge of controlling all the equipment, and the second one a web based subsystem. Relevant technical aspects in this approximation are explained in this section.

Following, a general architecture of the system is showed:

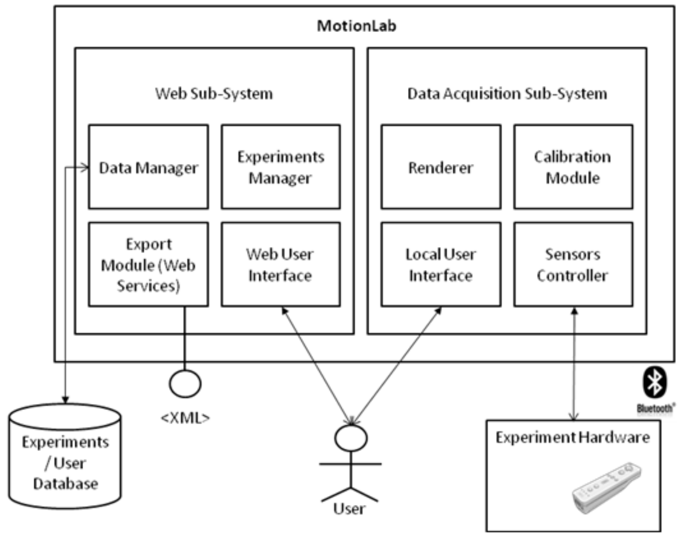

Figure 1. MotionLab Platform

As seen in Figure 1. , there are two main parts, the "Data Acquisition Sub-System" and the "Web Sub-System".

The first one is in charge of the acquisition and the data renderization, i.e. this sub-system controls the experiment hardware, calibrates the system, obtains data and then it makes the renderization process in order to represent it to the user through the local user interface.

a) The data acquisition sub-system manages and coordinates the modules of this sub-system and communicates with users through the local interface in order to receive orders and display information.

b) The graphics module is responsible for representing all information of the samples, sensors and application experiments. It draws and displays all the data in real time on the screen.

c) The Sensor Controller is the responsible of the communication with the experiment hardware and its sensors. It makes the connection with the Wiimote control and it receives data from its sensors in order to transmit them to the data acquisition sub-system.

The second one is in charge of the experiment management and the data exportation to third party systems, i.e. this sub-system manages all the experiments, user profiles, manages the experiment and the user database and exports the experiences to other systems using web services. Users can review the experiences and manage profiles using a Web user interface.

a) The data manager module is responsible of managing the system data at real time and to make them persistent. The database stores MotionLab projects, created from the web application and it can manage user permissions and projects stored in it. In addition, it can export experiment data to any physical storage medium.

b) Publications in the web site are done using web services, and all structured data are sent in XML format. Using web services enables to develop platform independent applications, making the system accessible for third parties (using a "Universal Description, Discovery and Integration" directory, UDDI).

c) Communication with other third party systems can be done through the "Export Module". It uses Web Services with structured data in XML. The use of standards of this technology provides extensibility and transparency.

d) This communication feature enables teachers from other locations to use all of the experimental data to their specific needs, without having their own laboratory.

Finally, .NET platform has been used for the system implementation as development environment, for both, data acquisition sub-system and web sub-system. Visual Studio 9.0 and C # development language have been used and for data persistence the database manager MySQL 5.0 has been used.

B. Wiimote

As mentioned before, Wiimote is the video game controller device developed by Nintendo for the Wii console. This remote control can be used for the development of positioning systems and it is a low cost device with a great performance.

Wiimote has three accelerometers, i.e. an instrument for measuring acceleration, detecting and measuring vibrations. The accelerometer built-in Wiimote is the ADXL330, a chip MEMS (micro electro-mechanical system) made by Analog Devices. This device is capable of measuring both acceleration and direction movement or rotation in three axes. Basically, the accelerometer operation is based on a piece of silicon, held to an end, and placed between the electric field exerted by two capacitors.

ADXL330 [8] is a small, thin and low voltage chip, which is composed of three accelerometers, one for each axis with variable voltage signal output. The device measures acceleration with a range of ± 3 g. It can measure the static acceleration of gravity in applications that require monitoring of tilt, as well as dynamic acceleration resulting from motion, shock, or vibration. The output signals are voltages that are proportional to the acceleration detected by the accelerometer. It offers an acceptable performance for the project and provides the following features: three axis sensors, small and thin potting (4 mm × 4 mm × 1.45 mm), low consumption. (200 uA to 2.0 V), a single point of supply (from 2.0 V to 3.6 V), shock tolerance 10,000 g and an excellent stability against temperature. It also contains a MOT (Multi-Object Tracking) sensor (engine vibration), a Bluetooth chip and a connection port for peripherals.

Silicon is in charge of transmitting the movement, when the Wiimote is moved, the silicon bar is closer to one of the capacitors, which makes the electric field changes, this change is detected and real-time translated into a motion. In Figure 2. , a Wiimote sketch can be observed.

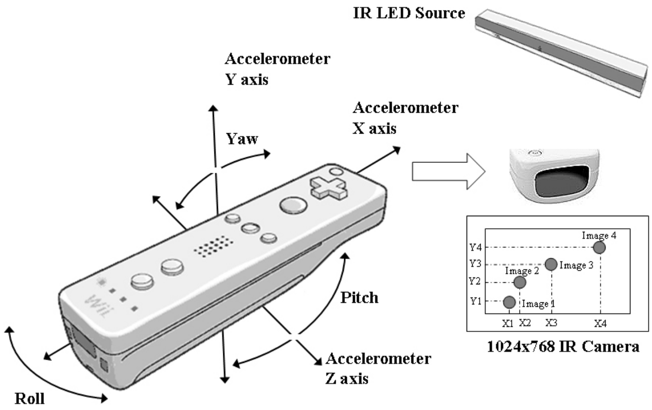

Figure 2. Wiimote

In the front of the Wiimote there is a translucent dark plastic, and behind it, it is placed the MOT infrared sensor made by Pixart Imaging. This sensor visually keeps tracks of multiple objects with a resolution of one megapixel. So to run, it needs an infrared source, consisting in this case of several LEDs arranged in a bar.

The Wiimote's sensor locates these LEDs, forming the ends of a "virtual display" that will be the relative action field. The computer screen acts, in this case, as a display.

To work properly the application must be set up, indicating the position of the bar and the aspect ratio of the display screen (16:9 or 4:3). In this way, the remote is able to continuously "know" its position in space and its accelerations in the x, y and z axis.

All data, motion detection and position are sent directly to the Broadcom Bluetooth chip (built in the remote). In addition, these data are sent from this chip to the computer's Bluetooth adapter where they are stored as well as real-time shown in the display. The recorded file can be exported in Microsoft Excel format in order to be treated (as for instance to represent the positions and accelerations of the studied solid).

III. EXPERIMENTAL CASE

A. *Types of Experiences*

The experience object to study is the uniformly accelerated one-dimensional motion of a mobile in an incline plane. This is done on a leaky aluminium pneumatic rail connected to an air pump so that the mobile object is moved on an air mattress. This air mattress hugely reduces the friction.

The experiment allows students to get practical knowledge about the following three aspects of kinematics and dynamics of one-dimensional motion:

1) Uniform Motion (UM). As shown in the equations (1), (2) and (3) is characterized by a linear dependence of distance over time: so the velocity is constant and there is zero acceleration. On the mobile object any force is working.

$$v = constant \quad (1)$$

$$a = 0 \quad (2)$$

$$x(t) = x_0 + vt \quad (3)$$

To make this experience, a fork is placed on each side of the mobile object. The uniform motion is accomplished by pressing the cradle of the mobile object against the top of the rail and leaving it free.

In the experiment the graphs (4) and (5) are displayed.

$$x = f(t) \quad (4)$$

$$v = f(t) \quad (5)$$

2) Uniformly Accelerated Motion (UAM). The equation which calculates the position is (8), the velocity is (7) and the acceleration is constant (6) as it correspond to a constant force.

$$a = constant \quad (6)$$

$$v(t) = v_0 + at \quad (7)$$

$$x(t) = x_0 + v_0 t + \frac{1}{2} a t^2 \quad (8)$$

This type of motion is achieved by tilting the rail. A flat piece of known thickness is placed under one leg (the supporting one) of the rail. Knowing the angle of inclination of the mobile, the mass and the acceleration obtained from experience, allows the students to verify the validity of the second law of Newton.

In the experiment the graphs (9) and (10) are displayed.

$$x = f(t) \quad (9)$$

$$v = f(t) \quad (10)$$

3) Collisions. The interest in this experiment is checking the law of conservation of linear momentum (11) and to distinguish whether the collision is elastic or inelastic taking into account the variation of kinetic energy, E_k.

$$p = m v \quad (11)$$

Two types of shock can be accomplished:

a) Elastic collision, it is achieved by putting two accessories in the ends of the mobile objects that will collide, a fork in the first one and an elastic accessory plate in the other one.

b) Perfectly inelastic collision, the two mobile after the collision must remain joined.

In the experiment the graphs (12), (13) and (14) are displayed.

$$x = f(t) \quad (12)$$

$$v = f(t) \quad (13)$$

$$E_k = f(t) \quad (14)$$

B. *Prototype*

Next figures (Figure 3. and Figure 4.) show two photographs of the prototype based on the platform MotionLab. In this case, MotionLab is being used as a data capture system for a low friction air rail. The pneumatic rail is an experiment that can be considered classic, which studies the kinematics and dynamics of solids in one dimension. The usual data acquisition devices for this experiment consist of a series of photoelectric cells, usually two, which besides being quite expensive only allows obtaining data in only two points of the track.

The pneumatic rail experiment consists of the following parts:

1) A pneumatic rail made of a square aluminium tube (63 mm x 63 mm), 2 m long, supported on three legs that allow levelling. It presents a series of holes through which pressurized air goes out, forming a pneumatic bed between the rail and the mobile object which minimizes friction. The air stream is supplied by a blower pump connected to the rail by a flexible hose.

2) Rail made of anodized aluminium, l = 130 mm, which can incorporate several elements.

3) Pluggable screen made of plastic, mountable on the rail to stop the rays of light from the photoelectric door. (L = 35 mm). This element is used in the classic experience and enables to obtain comparisons between MotionLab and the classic one.

A huge advantage of MotionLab is the data acquisition in a continuous way.

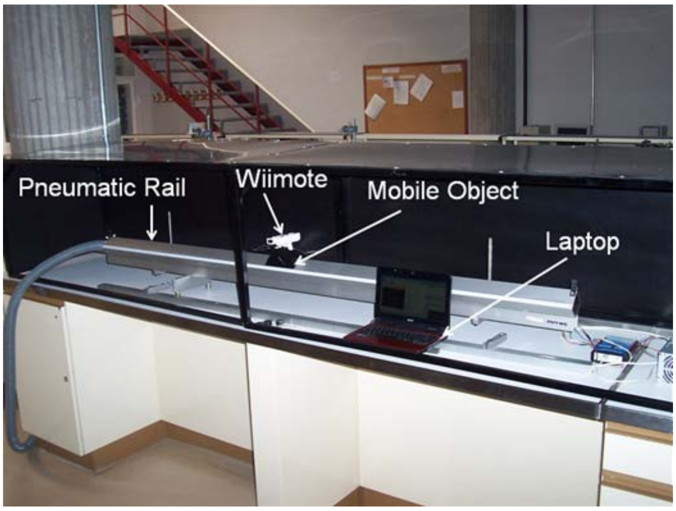

Figure 3. Prototype I

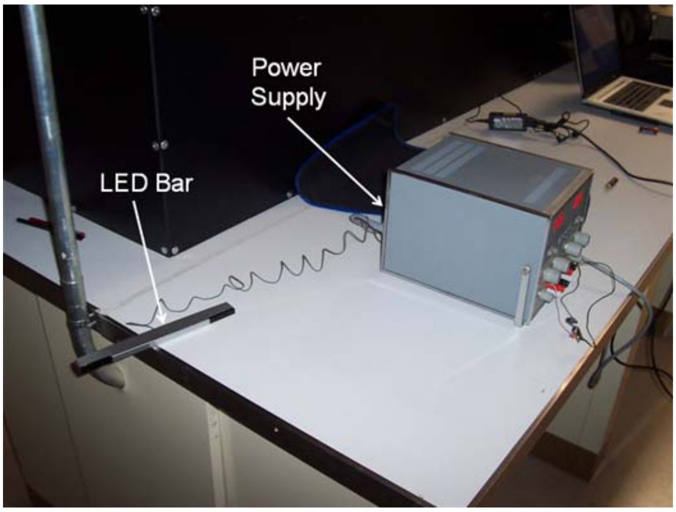

Figure 4. Prototype II

As shown in Figure 3. the experimental assembly basically consists of:

1) A Wii remote control (Wiimote), equipped with its corresponding sensors and placed on the mobile whose motion is being studied,

2) A computer (an ultraportable with a built-in Bluetooth adapter or a laptop perfectly suits the performance needs) and an infrared diode bar parallel located to the air rail and spaced about 1.5 m out (Figure 4. left).

C. Working with MotionLab

1) Getting samples

When a new sample is created, different options of calibration are possible, depending on the type of the selected experiment. Figure 5. shows the basic structure of the sample panel:

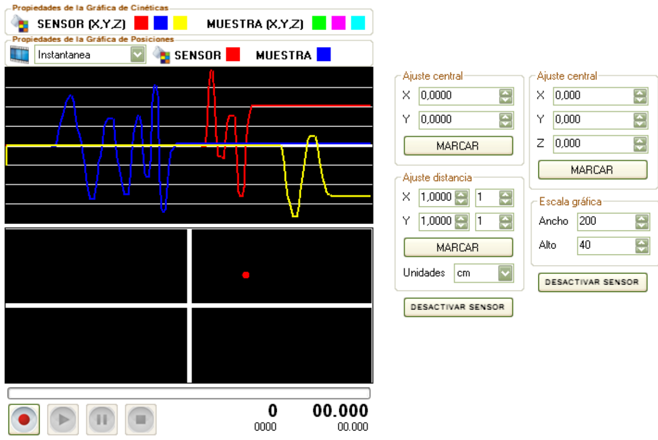

Figure 5. MotionLab Acquisition Application

In this panel, three elements can be seen:

a) Representation charts: in the top left, one or several charts represent real-time values obtained from the sensors.

b) Calibration panels: on the right of the charts, there are different options to configure and calibrate the sensor involved in the experiment.

c) Recording and playback panel: underneath the charts, the necessary buttons for recording and playback data from a sample can be found.

Before recording a sample, sensors must be calibrated. Depending on the sensor used, its placement and the characteristics of the physical experiment, parameters must be adjusted in different ways. MotionLab offers several automatic calibration tools to facilitate these tasks.

Once the sensor has been calibrated, the application is ready to record data obtained by each sensor, the procedure is the same for any of them. To start recording, simply press the record button. When the experiment is finished, users must just press it again to complete the data collection.

2) Configuring Experiments

To obtain an experiment is the main goal of MotionLab. An experiment consists of one or more samples combination. Once selected the samples of the experiment, students will configure them in order to have the experiment ready for analysis.

When students are working with an experiment, they can find, depending on the type of experiment, different charts and options. Figure 6. shows an experiment and all parts which it is composited (different samples, etc.).

Figure 6. Experiment

The main element is the centre panel where the samples selected for the experiment are rendered simultaneously. On the right, the list of experiment samples and the panel to configure them can be found. At the bottom the experiment playback buttons, its duration and some other controls are placed.

3) Exporting Experiments Data

With an already configured experiment, MotionLab offers several options to export data in different formats. This is an easy procedure in which both the experiment and the output data format is needed to select.

In the website all reports that students have published can be searched through the publication service. Then, all associated report data can be seen.

Next figures show some parts of the web sub-system, specifically Figure 7. shows the report management application. As show in the figure a form to enter search criteria is used to search experiments reports. It is possible to search by title of the experiment or by the author name. When the search is finished, all results contained in the specified text are listed. Each report has the author's name, a title report and date of execution as metadata.

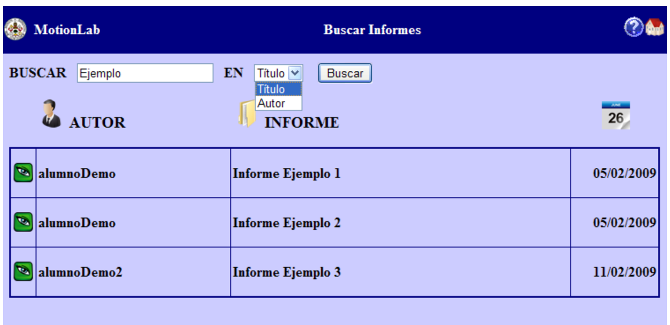

Figure 7. Report Management Application

In Figure 8. a report detail is shown as an example. All data that the report contains is displayed to the user.

Figure 8. Report Detail

Students who have published their reports can manage them using their credentials. They are able to view or delete them from the system using the web application. Only the owner or an administrator can manage them.

IV. ADVANTAGES OF MOTIONLAB

MotionLab provides significant advantages over the traditional experimentation systems. On the one hand, it substantially improves the cost per experiment, e.g. in some experiments a special paper is used for trajectories visualization in which the paper is literally "burned" by the moving object. This means a significant saving in cost per experiment and in cost per student.

TABLE I. shows a brief cost comparison between MotionLab and the classic laboratory:

TABLE I. COST COMPARISON

Modality	Cost	
	Element	***Total***
MotionLab	Wiimote, LED Bar, Power Supply	60 €
Classic	Equipment (photoelectric cells, etc.)	600 €

It also provides a greater cooperation among students and a higher apprenticeship allowing making comparisons among experiments of different groups of students which results in a higher quality education.

More advantages of this system are the following ones:

a) One of the most important advantages is that it is a very didactic system which enables the understanding of the experiment by the student far more quickly than with traditional systems.

b) Remote access. In order to allow students to conduct experiments from anywhere at any time, and remote controlling parameters of the experiment.

c) It is technologically advanced and the lab equipment has a better performance and it is available to students more time.

d) Distance courses. MotionLab allows the organization of engineering courses.

e) Autonomous learning. MotionLab promotes autonomous work, fundamental in the European Higher Education Space.

f) Furthermore these tools foster independent learning, as advocated by one of the main guidelines of the Bologna system marked by adaptation to ECTS (European Credit Transfer System).

g) *Cool factor,* wiimote has a very cool factor which is very important to encourage and motivate students in the learning process. Moreover, due to the fact that for engineering students laboratory and practices constitute a fundamental step in the learning process this is an aspect to take in account.

V. RESULTS

As shown in Figure 9. two experiments can be seen in the same graph. Both of them are plotted in two different inclinations of the plane. In the figure the curves with circles are those of the classic experiment using photoelectric cells while the curves with squares correspond to the experiment using MotionLab.

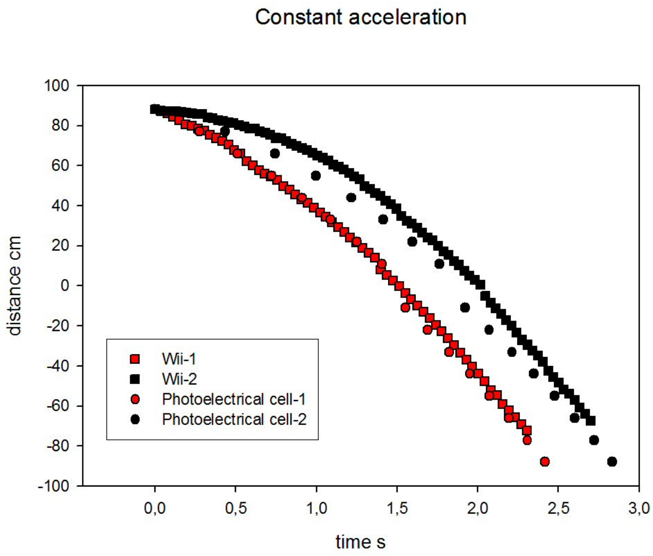

Figure 9. Comparison between MotionLab and the Classic Experience

As mentioned there are two graphs one of which shows the experience using MotionLab while the second one shows the results using the traditional experience with the photoelectric cell system that has the classic rail.

As it can be seen the experimental results are quite similar. But while the classic experience provides a smaller amount of data (limited to the number of photoelectrical cells), with the use of MotionLab a greater number of points are obtained, which enables to obtain more accurate results and closer to the theoretical model.

VI. CONCLUSION

The application of low cost sensors in building some real kinetic experiments have been presented. This is a low cost data acquisition system for physical experiments using the three-axis accelerometers and the infrared camera built in the Wiimote. The system has been used for experimentation of uniform motion, uniformly accelerated motion and several kinds of collision.

The results are really good according with the expected results. The system allows graphic visualization of the experiment and can be used to perform a wide number of experiments, for instance it can be used in all types of pendulums, simple, physical, coupled pendulums, springs... and generally in any experiment which involves motion.

This prototype has just been completed and although it has been tested in laboratory, it hasn't been used by students yet. The first tests will be done in this course (2009-10) and they will start soon.

Making real experiments, it has been found that the possibilities of the system would be increased if multiple sensors of the same type were simultaneously working. For instance, in some kinds of collision is really interesting to study the trajectories of multiple mobile objects in order to obtain a more complete experience.

Therefore, the addition of several Wiimotes is proposed as a future expansion to provide more functionality to the system. In fact, right now a new platform is starting to be developed and it will bring major improvements, like for instance including the ability to work with up to eight remote controls and incorporating a new more sensitive sensor (that Nintendo has just released last summer).

This second version is being developed using the LabVIEW graphical programming language instead .NET platform (it has been used in the prototype described in this paper). Nowadays using LabVIEW is a good option for remote laboratories and it has been used by some prestigious entities around the world [9] with good results.

The most remarkable thing of this work it is a low cost experience and quite easily applicable in any laboratory or educational institution that may be interested.

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