International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 8 Issue 6 Ser. 1 ǁ 2020 ǁ PP. 57-60

Physics experiments by Open-source systems

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ABSTRACT: *An open-source stage to be utilized in secondary school or college labs has been created. The stage allows the exhibition of elements tests in a basic and reasonable manner, consolidating estimations of various sensors in the stage. The sensors are constrained by an Arduino microcontroller, which can be remotely gotten to with cell phones or tablets. The stage establishes an efficient detecting option in contrast to business designs and can undoubtedly be reached out by including new sensors that expand the scope of covered examinations.*

I. INTRODUCTION

We have designed and constructed a low cost plat- form that can be used to do simple physics ex- perimentscombining differentsensors'dataeasily. The purpose of this work consist in implementing a cheap system that can be used in high schools and universities regardless of their budget in di- verseexperiments,allowingahighercustomization than equivalent commercialsets.

II. SYSTEM DESCRIPTION

The initial requirements of the system are afford- ability, simplicity, flexibility and extensibility. Un- dertheaffordabilityrequirement,wehavedecided to employ systems that can be easily found on the Internet at low prices. Simplicity means thatusers with little to no training can easily use the sys- tem in physics experiments without difficulty, but also, that its construction does not require special skills. Flexibilityimpliesthatthesystemshouldbe portable enough to work on different types of ex- periments. Finally, its extensibility will allowusers toincludeadditionalsensorsintheplatformtoen- hance its capabilities and to use it in new experi- ments.

Inordertoobtainaninnovativeplatformaswell as to add sharing features to it, almost exclusively open-source hardware and software components are used. Within this approach, the physics teacher community can work in open projects that can be used by other teachers, thus reducing the work of designing experiments with the platform. Follow- ingthiscondition,thecharacteristicsofthesystem are published under a public GNU license in the GitHub repository [1]. All the technical details of the platform hardware and software are detailed in that repository: software code, assembling dia- grams and technical characteristics of the compo- nents.

We initially decided to include sensors in the platform that measure kinematic magnitudes: ac- celerometer, gyroscope, distance sensor andlight- gatesensors.Othersensors,suchasamagnetome-

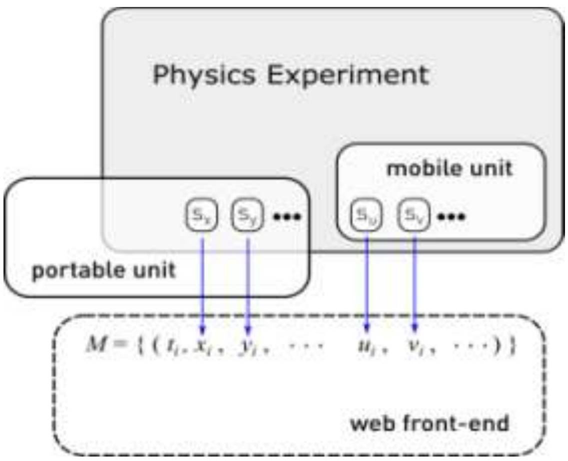

Figure 1: A conceptual diagram showing the main com- ponents of the system. It comprises a mobile unit that includes several sensors (s_u, s_v , ...) controlled by an Ar- duino board and a portable unit with a Raspberry Pi that communicates with the Arduino and establishes a Wi-Fi network. It can also host additional sensors (s_x, s_y , ...). The measurements of all the sensors can be transferred into the users' devices as series of vectors M via a web front-end implemented in the Raspberry Pi.ter,abarometer,athermometer,etc.,canbeeasily added later. Figure 1 shows a diagram of the use of the platform in a physics experiment: the plat- formincludesamobileunit,whichcanbeattached to a mobile body, containing sensors (s_u, s_v,... in the figure) and a portable unit responsible for the Wi-Ficonnectionthatallowstheusertoaccessthe measured data, but which can also include addi- tional sensors (s_x, s_y,... in the figure). Measured data are collected by the portable unit and orga- nized in vectors (M = (t_i, x_i, ...)) in the figure) also containing the time stamp of the measure- ments. Whenever it is desirable and possible, the mobile unit can be attached to a body in order to studyitsmovement.Then,theconnectionbetween the mobile and the portable units must be based on wireless communications, allowing the studied body and the attached unit to move freely. In our case,communicationsbetweenthemobileandthe portable units are performed viaBluetooth.

The design of the mobile and the portable units wasbasedonpreviousworksofembeddedsystems

[2] and they comprise the following elements:

Mobile unit: An Arduino Nano v3 controls a set of sensors. The version that has been tested in laboratory experiments included an infra-redlinetracker,amotionprocessingunit consisting of 3-axis accelerometer, gyroscope and an ultrasound distance sensor. The AT- MEL serial interface of the microcontroller is connected to a HC-SR06 Bluetooth device. A LiPo battery supplies power to all the system. In its current design, the motion processing unit can be replaced by a similar one thatalso includes a 3-axis magnetometer togetherwith theaccelerometerandgyroscopewhichwould permit to have a inertial measurement unit with9degreesoffreedom.Thissystemispro- grammedinArduino1.6[3]anditimplements asimpleprotocolthroughaserialwirelesscon- nection, which is established by using Blue- tooth connectivity that allows the initializa- tion of the microcontroller as well as starting andstoppingdataacquisition.Themainspeed limitationindatameasurementsofthesystem is due to the Bluetooth connection. Figure 2 (top)showsanimplementedmobileunitused insomephysicsexperimentsdescribedbelow.

Portable unit: It consists of a Raspberry Pi2 with Raspbian Jessie [4] as an operating sys- tem. The core process of the unit is pro- grammed in Go [5] and it governs the over- all system as well as offering a web front-end. This unit supports the Wi-Fi and bluetooth connections. The data recorded in the mea- surementsarestoredinaSDcard,constituting the local persistent storage unit. These data can be accessed and retrieved by the users' laptops or smartphones via Wi-Ficonnection. Additionaly,theportableunitcanalsoallocate otherwiredconnectedsensorsusingtheGPIof theRaspberryPi.Inthecurrentconfiguration of the system, four infrared emitter-receivers are connected to it. These can be used, for example, to measure instant speed at differ- ent points along the trajectory of a body. The unit can be powered by an ordinary USB bat- tery, allowing to do physics experiments out- side the laboratory. Figure 2 (bottom) shows the portableunit.

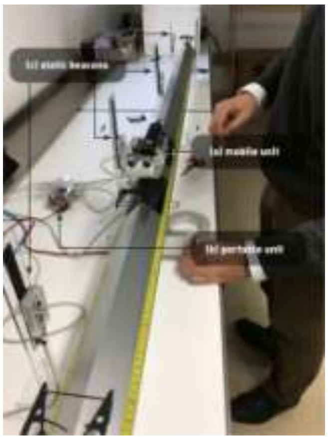

Figure 2: Mobile (top) and portable (bottom) units of the system. Portable unit shows the connections of four additional infrared sensors attached to it (connections A, B, C, and D in the figure).

III. USE IN THELABORATORY

The system described above can be used in differ- ent ways in the physics laboratory depending on the users' skill and knowledge of physics. We have tested the platform in two basic experiments: an air track in order to study an uniformly acceler- atedmovementandapendulumtoanalyzeperiodic motion and to obtain the gravity acceleration.Fig- ure 3 shows the mobile and portable units being used in the air track experiment. In this experi- ment,themobileunitincludeda3-axisaccelerom- eter, a 3-axis gyroscope and an ultrasonicdistance sensor. In addition, four static infrared beacons were placed at fixed points of the trajectory and connected to the portable unit. The sampling fre- quency was about 25 samples/s (Δt 0.0394 s). This frequency was the result of a compromisebe- tween the measuring capabilities of the Arduino and the data communication limitations between the Arduino board and the Raspberry, using the bluetooth connection. With the arrangement of sensorsusedintheexperiment,userscanmeasure the cart acceleration (accelerometer), average ve- locities between different points (infrared beacons), and the change in the position with time (ultra-soundsensorandinfraredbeacons).Fromthedata

Figure 3: Photography of an air track experiment us- ing the platform. While the mobile unit is on the mov- ing cart, the portable unit stays on the table with four static infra-red beacons connected to it.

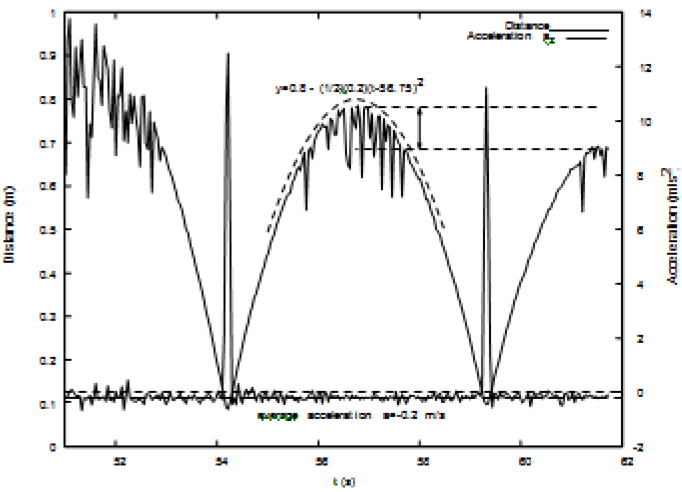

Figure 4: Example of combined data recorded with the platform in an air track experiment. The dependence of the distance and the acceleration along with the di- rection of movement recorded in the same experiment are shownjointly

recorded by the different sensors, the user can an- alyze the uniformly accelerated movement andthe relationships between kinematics magnitudes. On the other hand, in a pendulum experiment, users cancombinetheaccelerometerandgyroscopemea- surements to study the acceleration and speed in different points and the periodic dependence of both magnitudes. Infrared beacons can also be used to measure the passage of time at different points of the pendulum trajectory and enrich the physicalmeasurements.See[6]formoredetailson an air track experiment.

Recorded data are stored in the SD card as a plain CSV file with data of all the sensors used in the experiment. The CSV files are transferred to the users' computer or mobile devices usingthe Wi-Fiestablishedbytheportableunit.Therowsof the CSV file are tagged with the acquisition time, in order to ease the analysis of the data by sim- plyimportingthefileonanyspreadsheetprogram. Figure 4 shows some results of the measurements with the air track. The measurements of the ultra- sounddistancesensorandthecomponentoftheac- celerometeralongthedirectionofthemovementare represented as a function of time. From the data shownthere,itcanbeobservedhowtheexperimen- talnoiseoftheultrasoundsensorincreasesnotice- ably with the distance to the reflecting screen. We havecheckedthisnoiseand,accordingtoourexper-

IV. DISCUSSION

A cheap open-source system to be used in simple experiments has been developed. It comprises the hardware and software of a sensorized platform. The technical characteristics and the control soft- wareofthesystemcanbedownloadedforfreefrom the Github repository [1]. The system permits the measurement of different magnitudes in the same experimentandtheanalysisofvariousphenomena. The electronic components used in the systemcan beacquiredontheInternetbylessthan100e,and additionalcheapsensorscanbealsoincluded.Un- likecommercialsensorsystems,thisoneconstitutes an extensible and customizable platform thatcan

Figure 4: Example of combined data recorded with the platform in an air track experiment. The dependence of the distance and the acceleration along with the di- rection of movement recorded in the same experiment are shownjointly.iments,itisduetotheairexitingfromtheairtrack holes. Reducing or eliminating the airtrackpump- ing,thatnoisedrasticallydecreases,aswellaswhen the distance between the sensor and the reflecting screen decreases. This can be seen as a possible limitation of the used sensor, which can be solved using,forexample,anopticaldistancesensor.The superposition of the data from the accelerometer anddistancesensorsallowsaclearidentificationof the collision events between the cart and a rub- ber band at the end of the air track. From the diferenceindistancesreachedafterconsecutivere- bounds(markedasexampleinthefigure)userscan obtain the restitution coefficient of the collision. Complementary, from the accelerometer data, users canobtainthechangeinspeedduringeachcollision and compare that result to the one obtained by analizyng the maximum distance before and after the bounce. As an illustrative result, a parabol- lic curve $y = 0.8 \quad (1/2)0.2(t \quad 56.75)^2$is shown in the figure. The distance 0.8 was chosen to dis- placealittlethetheoreticalcurveupwardsoverthe experimental points for clarity. be modified by adding other sensors and includ- ing other software characteristics. The use of the Githuprepositoryalsoallowsthecollaborationbe- tweenusersthatcanaddnewcharacteristicstothe platform.

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