

Integration of Automatic Procedures for Acquisition, Processing, Storage, Analysis and Monitoring of Experimental Data in Physics Education

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Abstract: The acquisition of experimental data and their processing in real time is an important problem on which depends the didactic efficiency in teaching and learning Physics at secondary level using the STEM educational model. A viable solution to this problem is the use of microcontroller boards and of sensors. In this sense, we have developed teaching tools based on the Arduino Uno development boards and an ecosystem of sensors used both in experiments and in Physics projects. Interpretation and analysis of experimental data were performed using the Microsoft Data Streamer add-in for Excel. In this paper are presented a series of results obtained through the implementation and testing of these modern educational tools, very important for Physics teachers.

Keywords: Arduino Uno, sensors, Data Streamer, data acquisitions, Bluetooth communication

1. INTRODUCTION

Arduino boards paired with an ecosystem of sensors can be used in most Physics Educations experiments (Orgatini, 2018; Moya, 2018; Sari and Kirindi, 2019; Kotseva et al., 2019; Coban and Coban, 2020; Chen et al., 2022; Singh et al., 2022). That is precisely why we designed and created educational kits composed of Arduino Uno boards and sensors, intended to support the process of acquisition, processing, transmission, storage and analysis of experimental data. They represent a low-cost solution that should not be missing from a modern school Physics laboratory (Heo and Jung, 2018; Shaari and Berahim, 2021). In the following, we will present the content of such a kit and how it can be used to build digital laboratory instruments whose efficiency is qualitatively reflected through practical works and projects converging to scientific research standards.

2. EXPERIMENTAL KIT

The basic contents of such a kit are as follows: Arduino Uno board, sensors for Mechanics (acceleration, sound, ultrasound), Thermodynamics (temperature, pressure, gas detection), Electricity (current, voltage, electrical power), Magnetism (Hall effect sensor) and Optics (ambient light, infrared) experiments, 16X2 LCD display, Bluetooth communication module, USB cable for connecting the board to the computer, connecting wires, breadboard, digital multimeter, wire pliers, magnifying glass (Fig. 1).

Additionally, for the implementation of Applied Physics projects and for the remote monitoring of the studied physical quantities, in the kit can be added an additional set of sensors, actuators, WiFi modules and a development board with a greater connectivity and memory (Arduino Mega).

The low price of an Arduino kit with basic educational content has determined that the purchase of such a set of kits,

for equipping a STEM laboratory, is a low cost investment, easy to apply in practice and with a remarkably fast qualitative educational feedback.

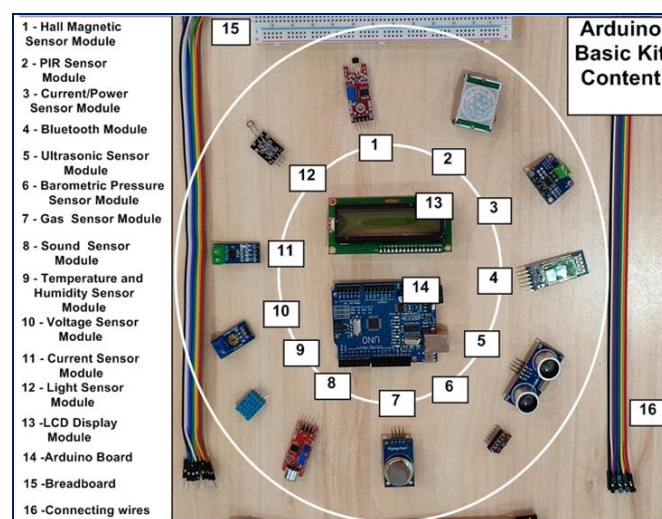


Fig. 1. Basic content of the Arduino educational kit.

Since the programming language for the Arduino boards is a simplified, easy-to-use version of the C++ language, the codes for the data acquisition experiments were written without difficulty. In general, most teachers who teach Physics from a STEM perspective already have a basic knowledge of programming in C/C++, so programming the Arduino board should not be a problem. In the same way, in the case of students, the control structures are studied in secondary school so that even for them writing and interpreting a code in C++ does not present difficulties. On the other hand, most of the code written for Arduino experiments and projects can be found on the Internet (the Arduino Forum community is an example of this). The latest sensor libraries (including their updates) can be downloaded from Github (a cloud service that helps developers store and

manage source code, as well as track and control all changes to source code).

Due to the extremely diversified current commercial offer of sensors and actuators, the scope of the experimental activities developed with this kit included most of the laboratory works provided in the Physics curriculum. The kit can be used for interdisciplinary projects across the entire STEM curriculum area. The advanced model of the kit (with additional sensor and actuator content) has been used for IoT and Robotics projects.

3. DATA STREAMER FOR EXCEL

Data Streamer is an Microsoft Excel add-in that enables the acquisition, monitoring, processing and analysis of experimental data taken from different sensors (Fig. 2). The application was downloaded from the Microsoft website and installed as an add-in in Excel.

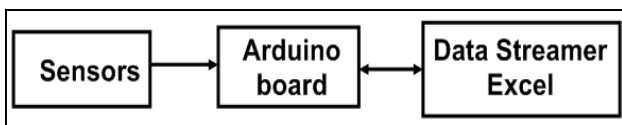


Fig. 2. Principle diagram of data acquisition with Excel Data Streamer.

Depending on the distance between the Arduino board and the computer running the Data Streamer application, we encounter the following situations: a) USB Arduino-computer connection (short range wired connection) and b) Arduino-computer Bluetooth connection (short and middle range wireless connection). In the following, we will present the procedure for transferring the data taken by the sensors, using these two connections.

3.1 Data acquisition from sensors via USB connection Arduino - computer

To test the acquisition, processing and monitoring of experimental data via USB connection between the Arduino board and a computing unit we created an experimental configuration whose scheme is shown in the Fig. 3.

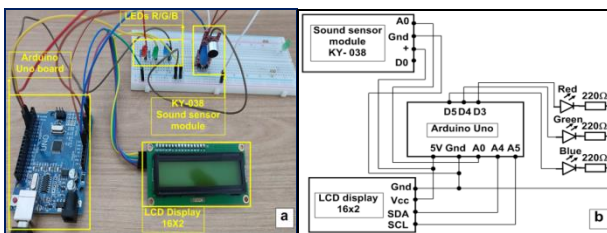


Fig. 3. Experimental configuration (a) and Data acquisition scheme (b).

It is a simple system for monitoring, in real time, the sound intensity level (in dB) in the ambient environment (Nurjannah et al., 2017). For data acquisition we used the KY-038 module, equipped with a sound sensor (microphone) and an preamplifier (based on the LM393 comparator). This module is powered at a voltage between 4÷6V, has a high sensitivity, has a low noise level and offers an amplification of about 20dB. It should be mentioned that the module has analog and digital output pins, the sensitivity being adjustable

with the help of a trimmer potentiometer. In the experiment we used the analog signal pin.

After uploading the code on the Arduino board we monitored the evolution of the experimental results both graphically and numerically, using the Serial Plotter and Serial Monitor tools from the Arduino IDE and Data Streamer respectively (Fig. 4).

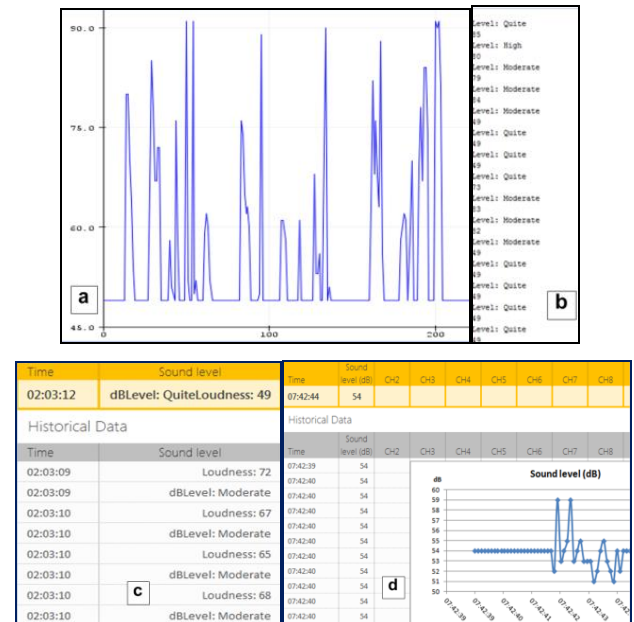


Fig. 4. Sound level monitoring in Serial Plotter(a), Serial Monitor(b) and in Data Streamer (c,d).

3.2 Data acquisition from sensors via Bluetooth connection Arduino-computer

Given that the Arduino board - sensors assembly is at a relatively large distance (meters-tens of meters) from the computer on which the Data Streamer Excel application is installed, the transmission of experimental data can be carried out via a Bluetooth wireless connection Arduino - computer.

We created the experimental configuration and tested the data transmission via Bluetooth connection between the Arduino board (equipped with the HC-05 Bluetooth module) and a computing unit (equipped with a Bluetooth adapter). In Fig. 5 shows the stream of experimental data transmitted via Bluetooth connection and monitored with Data Streamer.

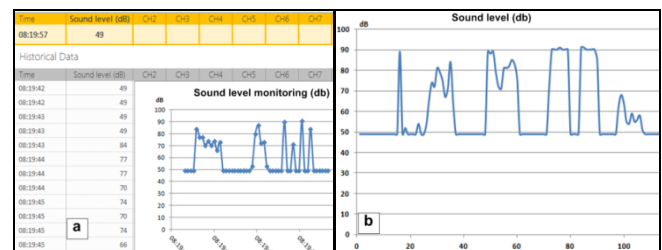


Fig. 5. Sound level real-time monitoring (a) and Analysis of recorded data (b).

In this way, the Bluetooth connection was functionally verified for remote monitoring of the data transmitted by the Arduino.

fter presenting and testing these two types of connections (USB and Bluetooth respectively) for data transfer between an Arduino board and a computer that has the Data Streamer Excel application installed, we will show how digital laboratory instruments can be made for acquisition, processing, transmission and real-time monitoring of data and how they can be used in school Physics experiments.

A quick comparative analysis performed between the two methods of acquisition and real-time monitoring of experimental data (Serial Monitor/Serial Plotter Arduino respectively Data Streamer Excel) clearly indicated the advantages offered by the Data Streamer application.

We have noticed that recording and analyzing the data taken from Serial Monitor is a laborious and slow operation that involves an extensive chain of activities such as: selecting the data field, saving them in .csv file, exporting them to Excel, graphically representing them. These intervention activities disrupt the continuity and fluidity of the data acquisition and monitoring process and are accompanied, in most cases, by the appearance of registration and processing errors. In addition, the graphs in the Serial Plotter interface only provide general indications on the temporal evolution of the studied physical quantities, the user not having direct access to the exact coordinates of the graph points for a precise local analysis of the evolution of the values of these quantities. On the other hand, in the interface of the Data Streamer application we can simultaneously view the numerical values of the data and their graphical representation. We can continuously monitor the data, record it, save it, import it and analyze it later easily and quickly.

Microsoft Data Streamer for Excel has introduced a new qualitative level in the process of acquisition, processing and real-time monitoring of the flow of experimental data. It also opened the doors of IoT to the Physics laboratory and brought STEM data acquisition experiments to standards compatible with NGSS (Next Generation Science Standards) and ISTE (International Society for Technology in Education) requirements.

4. DISTANCE MONITORING TOOL FOR MECHANICS EXPERIMENTS

To configure this tool we used the following materials: ultrasonic distance sensor module (HC-SR04), Arduino board, breadboard, connecting wires, 16X2 LCD display. The HC-SR04 ultrasonic module is one of the most widely used distance sensors. It is composed of two ultrasonic transducers. One is a transmitter that generates trains of ultrasonic pulses with a frequency of 40 kHz and the other is a receiver that detects waves reflected by an object located in the path of the ultrasonic beam. The module has 4 pins: Vcc, Trig (trigger), Echo, Gnd (ground) (Fig. 6). It operates at a voltage of 5V, consumes a current of 15mA and detect with a very good precision (of 3mm) objects located in the range of 2cm ÷ 4m. The ultrasonic beam angle of is below 15 degrees.

The principle of the measurement method is simple (Zhud et al., 2018).

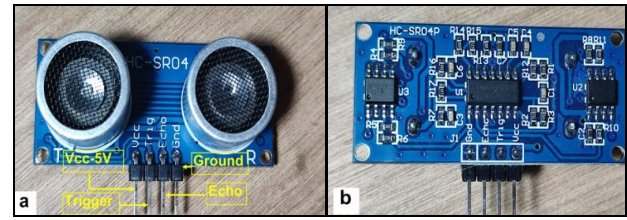


Fig. 6. HC-SR04 sensor module, front view(a), back view(b).

When the emitted wave front meets an object in the direction of propagation, it reflects and returns to the module, being detected by it. By determining the round-trip time Δt of the ultrasonic wave front, the distance Δd between the sensor and the object is calculated with formula $\Delta d = v \cdot \Delta t / 2$, where v is the speed of sound in air (approximate 340m/s).

4.1 Data Acquisition from ultrasonic sensor module via USB connection Arduino - computer

The experimental setup and electrical connections diagram between the HC-SR04 module and the Arduino board can be found in Fig. 7.

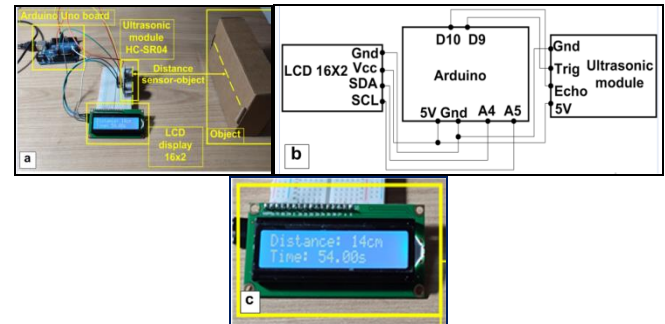


Fig. 7. Experimental setup (a), Electrical connection diagram (b) and Experimental data displayed on LCD 16X2 (c).

Sequences from the code loaded on the Arduino board and experimental results from Serial Monitor can be seen in Fig. 8.

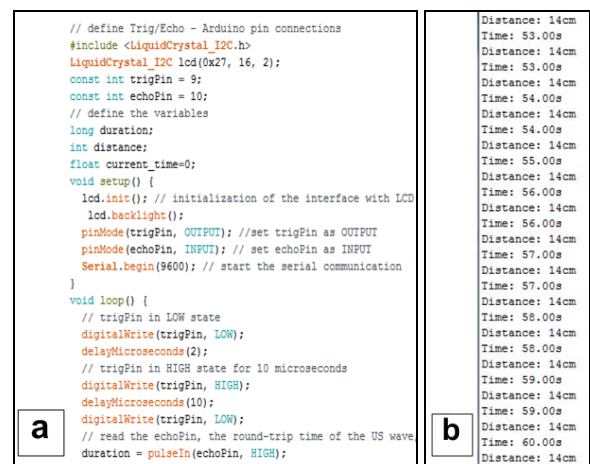


Fig. 8. Code sequences uploaded on Arduino (a) and Measured distance values displayed in Serial Monitor (b).

Given that the position of the sensor in relation to the objects in its coverage area changes continuously, we can use the Data Streamer application to monitor, analyze and interpret the data flow taken from the sensor. We monitored the evolution of the amplitude values of a mechanical oscillator made with the help of a non-deformable plate placed horizontally, fixed by rigid wires to the free end of an elastic spring suspended vertically from a tripod. We fixed a mobile phone on the platform. Under the platform, in a fixed position, we installed the HC-SR04 ultrasonic module, oriented so as to ensure a vertical emission-reception of ultrasonic flow (Fig. 9a,b). An application installed on the mobile phone, Linear Accelerometer (from the Physics Toolbox suite), which uses the data taken from the phone's acceleration sensor, additionally gave us the possibility to monitor the time evolution of the acceleration of the oscillating system. The results of monitoring the evolution over time of the amplitude of this oscillator, obtained with Data Streamer are illustrated in Fig. 9c,d. Both the harmonic oscillations of the system and the damped ones were monitored.

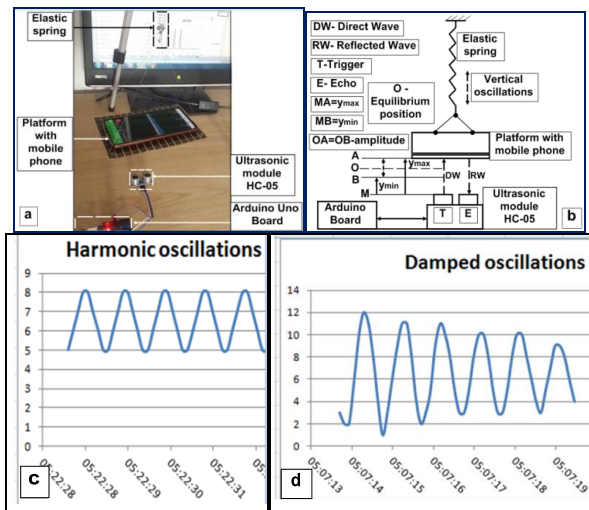


Fig. 9. Experimental setup (a), Experimental configuration diagram (b), Data Streamer graph of harmonic oscillations (c) and damped oscillations (d).

From the analysis of the graphs in the Fig. 9c,d the students understood that the oscillations of an elastic medium are, in general, damped oscillations and that the harmonic oscillatory regime occurs under special conditions: small-amplitude oscillations or sustained oscillations. Also from the analysis of these graphs, more precisely from the monitoring of the amplitude and frequency of the oscillations, the students studied the phenomenon of the superposition of the oscillations, produced by the interference of the oscillating system with external disturbing factors, of a mechanical nature.

4.2 Data acquisition from ultrasonic sensor module via Bluetooth connection Arduino - computer

Fig. 10 shows an example of using Data Streamer application to monitor, via Bluetooth, the distance to the walls of a maze of a mobile educational robotic platform equipped with an ultrasonic sensor and a Bluetooth module HC-05.

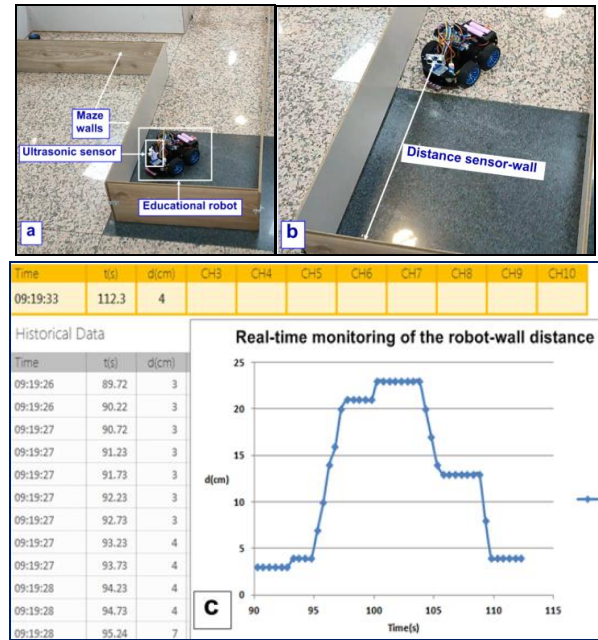


Fig. 10. Mobile robotic platform in a maze (a,b) and Continuous monitoring of distance to walls with Data Streamer (c).

The physical configuration of the tool for ultrasonic distance measurement was easy to achieve and the code used was intuitive. The instrument allowed the operational measurement of distances, with good precision. In the field of applications of this tool we have included, among others: the automatic control of the water level pumped into a container, the creation of a perimeter protection system for certain exhibition objects in laboratories, the measurement of gravitational acceleration in Physics experiments, the equipping of autonomous educational robots (obstacle avoiders), created within the school Robotics club.

5. TEMPERATURE MONITORING TOOL FOR THERMODYNAMICS EXPERIMENTS

To configure this tool we used the following materials: temperature and humidity sensor module DHT22, Arduino board, breadboard, connecting wires, 16X2 LCD display. This module measures temperature and relative humidity. It provides high measurement accuracy. It consists of a capacitive sensor for measuring humidity and a thermistor for measuring temperature. The module can be powered by both 3.3V and 5V DC and it can measure temperatures in the range $-40^{\circ}\text{C} \div 80^{\circ}\text{C}$, with an accuracy of $\pm 0.5^{\circ}\text{C}$ respectively the relative humidity in the range $0 \div 99.9\%$, with an accuracy of $\pm 2\%$. The output signal is digital. The module has 3 pins: Vcc (+), Gnd (-) and OUT (digital output) (Fig. 11).

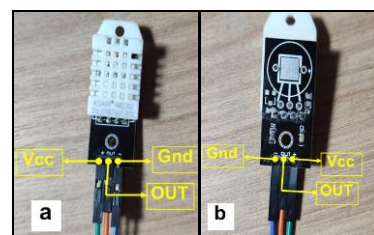


Fig. 11. DHT22 sensor module, Front view(a), Back view(b).

5.1 Data acquisition from temperature and humidity sensor module via USB connection Arduino - computer

The experimental configuration, the diagram of the electrical connections, code uploaded on Arduino and experimental results displayed in Arduino Serial Monitor are illustrated in Fig. 12.

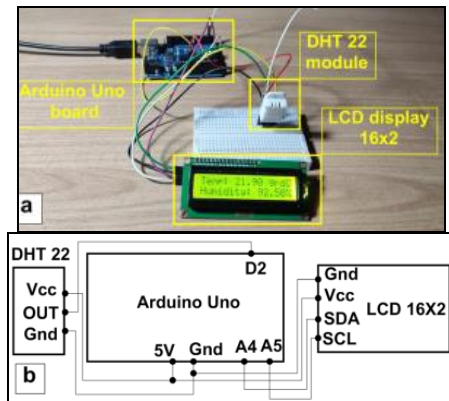


Fig. 12a,b. Experimental setup (a), Electrical connection diagram (b).



Fig. 12c,d. Code uploaded on Arduino (c) and Experimental results (d).

The Fig. 13 shows the data monitoring diagram using the Data Streamer application.

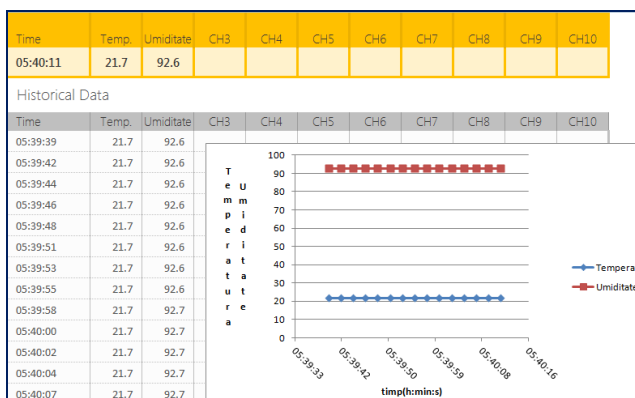


Fig. 13. Temperature and relative humidity real-time monitoring data with Data Streamer.

5.2. Data acquisition from temperature and humidity sensor module via Bluetooth connection Arduino - computer

An interesting practical application made with this sensor (DHT22) consisted in the remote monitoring, via Bluetooth connection, of the air flow temperature evolution produced by the cooling system fan of a video projector in a Physics laboratory, during an ON-OFF cycle. The data recorded by the Data Streamer can be found in the graphic representation in Fig. 14.

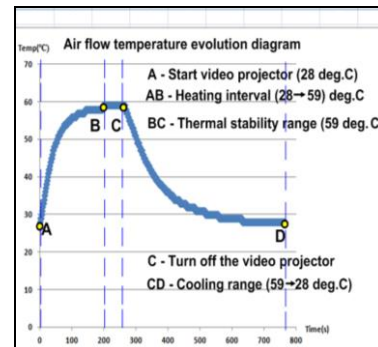


Fig. 14. Diagram monitoring the temperature of the air flow produced by a cooling system fan of a video projector.

From the analysis of the graph in Fig. 14 students understood that the heating-cooling process of the lamp of a video projector from the ambient temperature to the nominal operating temperature and vice versa must be a slow one, controlled by an efficient cooling system, in order not to affect, through processes sudden expansion-contraction, the material from which the lamp is made. The physical and logical configuration procedures of the ambient temperature measuring instrument proved to be creative and engaging activities. The temperature measurement was remarkably accurate. We have extended the spectrum of applications of this tool to: creating a school weather station, measuring the thermal gradient, vertically, in the Physics laboratory, measuring the temperature difference (outdoor-indoor) in the area of classroom windows, monitoring the temperature in a room sealed in Thermodynamics experiments, IoT monitoring of classroom temperatures.

6. VOLTAGE AND CURRENT MONITORING TOOL FOR ELECTRICITY EXPERIMENTS

To configure this tool we used the following materials: current measurement module based on the INA219 chip, Arduino board, breadboard, connecting wires, 220Ω resistor, 16X2 LCD display.

This bidirectional current sensor allows measuring currents up to 3.2A with a resolution of $\pm 0.8\text{mA}$ and voltages up to 26V. It supports supply voltages in the 3.3÷5V range. The module is presented in Fig. 15.

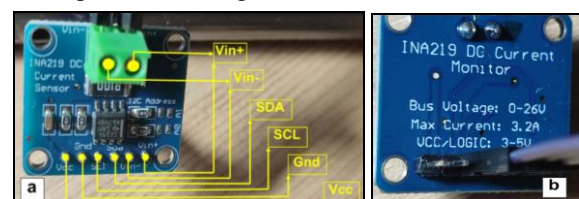


Fig. 15. INA219 sensor module, Front view(a), Back view(b).

6.1 Data acquisition from current sensor module via USB connection Arduino - computer

Connecting the module with the Arduino board, code sequences and experimental results displayed in Serial Monitor can be viewed in Fig. 16.

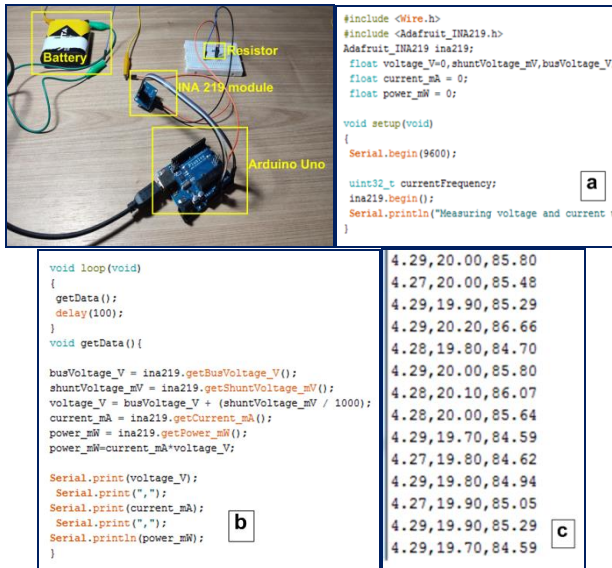


Fig. 16. Experimental setup and Arduino code (a, b, c).

We used the Data Streamer to plot the current-voltage (I-U) characteristic for verify Ohm's Law. The experimental setup, its scheme and the results obtained are shown in the Fig. 17.

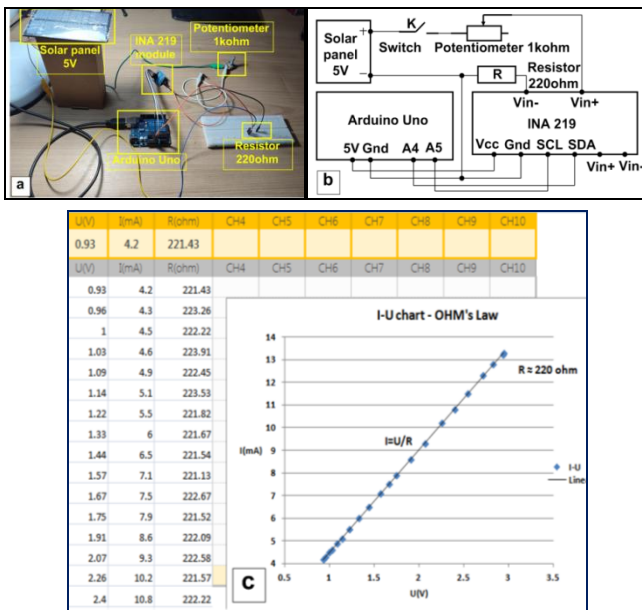


Fig. 17. Experimental setup to verify Ohm's law (a), Electrical diagram (b) and Graphical representation of Ohm's law (c).

The graph in Fig. 17 allowed students to quickly understand one of the most important laws in Electricity: Ohm's Law. They observed that for a homogeneous electroconductive medium, the ratio between the value of the voltage applied to it and the current passing through it remains constant. Comparing the graphs obtained from different conductive materials tested experimentally, they deduced that each

material has a specific electrical resistance (resistivity) and implicitly presents a specific electrical conductivity.

6.2 Data acquisition from current sensor via Bluetooth connection Arduino - computer

Using this sensor (INA219) and a Bluetooth connection we remotely monitored the functional parameters (U(V), I(mA) and P(W)) of an LED projector, powered by means of a 12V/7Ah battery, connected to a 50W solar panel (Fig. 18) (Houssem et al., 2019).

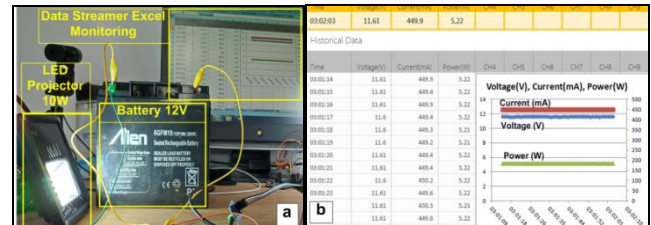


Fig. 18. Experimental configuration (a) and Parameter monitoring (U(V), I(mA), P(W)) with Data Streamer (b).

The physical assembly and programming of the current (and voltage) measuring instrument represented activities with a slightly higher degree of complexity than in the case of the distance and temperature measuring instruments. This was compensated by the very good results obtained with this tool in the developed experimental activities. The instrument has fully demonstrated its usefulness and efficiency in the most varied experiments of Electricity. We have included in the tool's range of applications: IoT monitoring of the functional parameters of a photovoltaic panel system used to power some automatic LED night projectors, Bluetooth monitoring of the charge level of a photovoltaic-powered electric battery.

7. LIGHT INTENSITY MONITORING TOOL FOR OPTICS EXPERIMENTS

To configure this tool we used the following materials: BH1750 light intensity measurement module, Arduino board, breadboard, connecting wires, 16X2 LCD display.

It works at voltages between 3 and 5V. It covers an illuminance range between 1 and 65535 lux, ensuring a measurement accuracy of 1 lux. The module and its pin configuration can be found in the Fig. 19.

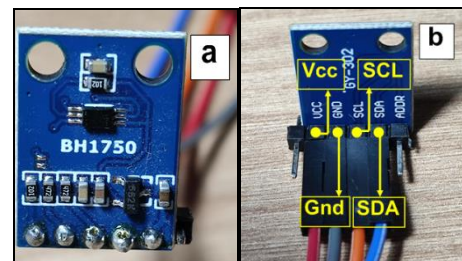


Fig. 19. BH1750 module (a) and pin configuration (b).

This module (BH1750) is dedicated to monitoring lighting in ambient spaces (Desnanjaya et al., 2022). It is used to automatically adjust the display brightness of mobile phones and LCD screens according to the ambient brightness. It also ensures the automatic operation of street lights, automatically

turning on or off the headlights of a car depending on the external lighting.

7.1 Data acquisition from light sensor module via USB connection Arduino - computer

The experimental setup, the wiring diagram, the code loaded on the Arduino and the values displayed in the Serial Monitor can be seen in the Fig. 20.

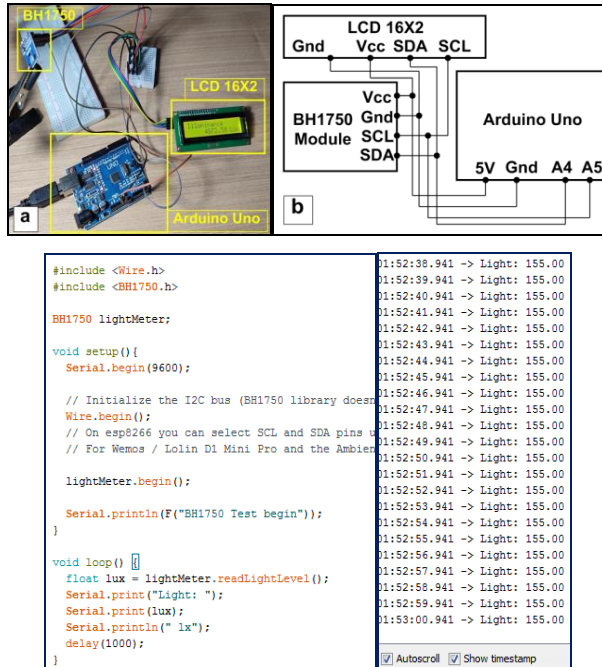


Fig. 20. Experimental setup Arduino-BH1750 module (a), Electrical connection diagram (b) and Experimental results in Serial Monitor.

The monitoring of the illuminance level in a room under the conditions in which different light sources are switched ON-OFF, can be seen in Fig. 21.

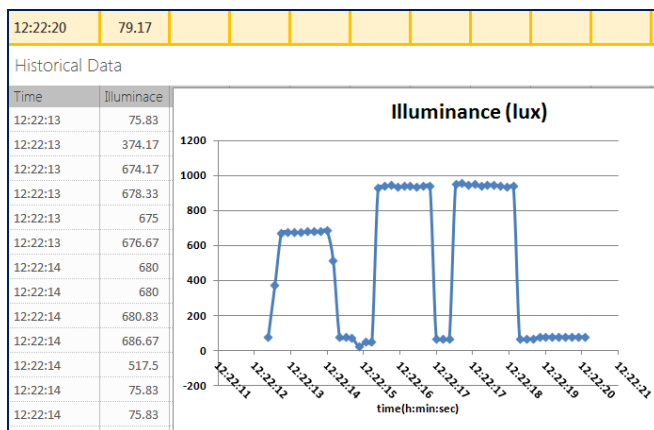


Fig. 21. Monitoring the illuminance level in a room with Data Streamer.

7.2 Data Acquisition from light sensor module via Bluetooth connection Arduino - computer

Also with this sensor we monitored, through a Bluetooth connection, the values of the illuminance $E(\text{lux})$ depending

on the distance $r(\text{m})$ at which the BH1750 sensor was placed from a laboratory light source, to verify the inverse square law for light (Fig. 22) (Voudoukis, 2017).

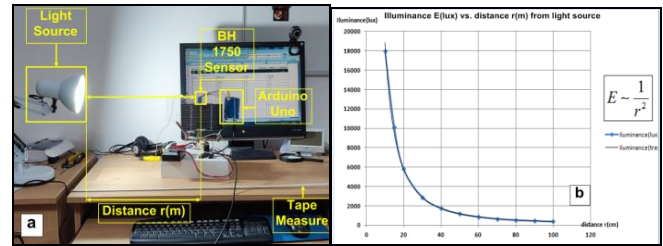


Fig. 22. Experimental setup for verifying the Inverse Square Law for light (a) and Experimental results recorded and processed with Data Streamer Excel (b).

The graph in Fig. 22b gave the students a clear understanding of the variation of illuminance with distance. They observed that the points of the graph follow the inverse square law with remarkable precision. Comparing the graphs of the variation with the distance from the source of illuminance and sound intensity, they understood that this law applies not only to optical fields but also to acoustic fields. Extending their observations, they found out that the law is generally valid for electromagnetic and gravitational fields.

The hardware-software configuration activities of this tool were extremely operative. Experimental tests have confirmed the stability and good precision in measuring the level of illumination with this instrument. More precisely, we compared the values measured by this tool with those displayed by the applications installed on different mobile phones (which use their ambient light sensors) and found variations of the average values within the limit of 5%.

We have integrated this tool in projects such as: automatic switching ON-OFF for the LED projectors used for the night lighting of the school (depending on the brightness level in the environment), automatic rotation of a solar mini-panel after the maximum solar light intensity, IoT monitoring of natural lighting, over a long period, in the geographical area of observations.

8. CONCLUSIONS

In the specialized literature, numerous examples of the use of previously mentioned sensors and microcontroller boards can be found for the creation of tools dedicated to the monitoring of experimental data in Physics Education. We will review some of these examples.

In a recently published study, (Coban and Salar, 2023) showed how classroom experiments with Arduino and the HC-SR04 ultrasonic sensor can be developed to plot distance-time, velocity-time and acceleration-time graphs for a moving mobile with constant acceleration. The authors conclude that such lessons provide students with an important educational gain for developing digital literacy and graphical data analysis skills. In another study, (Buachoom et al., 2019) showed how the HC-SR04 ultrasonic sensor can be used together with the Arduino Uno board to study the harmonic oscillatory motion of a body suspended by an elastic spring. Experimental data were graphed and analyzed in real time in

Excel. The authors conclude that such interdisciplinary STEM activities help students improve both their experimental and theoretical skills. Also, (Shoib et al., 2021) designed a simple experiment based on Arduino and the HC-SR04 sensor to determine the acceleration of a free-falling object (gravitational acceleration). From the slope of the distance vs. time squared graph, the value of the gravitational acceleration was determined, obtaining a good agreement with the value calculated by the standard kinematic equations.

Systems for monitoring atmospheric parameters play a particularly important role in our lives. In a recent paper, (Mabrouki et al., 2021) have shown how the DHT22 sensor can be used together with the Arduino Uno board and the ESP8266 WiFi module, in an IoT system for monitoring atmospheric temperature and humidity.

(El Hadi et al., 2021) presented how the mathematical formulas describing the charging and discharging of a capacitor can be obtained experimentally, using a device based on an Arduino board and the INA219 sensor. The created device made it possible to follow the temporal evolution of the voltage and current at the terminals of a capacitor. The experimental measurements were in excellent agreement with the theoretical predictions. The authors conclude that such a low-cost, small-sized device, which ensures good measurement accuracy, can be used for Electricity experiments, constituting an educational alternative to expensive laboratory equipment (oscilloscope, voltmeter, generator). In another study, (Aman et al., 2023) have shown how a voltage and current monitoring tool can be made through the ThingSpeak IoT platform, using the INA219 sensor together with the ESP32 WiFi development board.

(Naing et al., 2020) presented a system for monitoring the intensity of solar radiation and the level of UV radiation using the light intensity sensor BH1750 and the UV radiation sensor ML 8511. The experimental data obtained were simultaneously displayed on a 20X4 LCD module and recorded in an Excel spreadsheet through the PLX-DAQ application. In another article, (Hachmi et al., 2022) showed how an educational device based on Arduino Uno and BH1750 light sensor can be created to perform laser light diffraction experiments and graphically visualize the light intensity distribution in space. The results were graphically displayed in real time on the computer using the Excel Data Streamer add-in.

Based on these examples, we have created a diverse set of digital laboratory tools, dedicated to experimental works in the Physics school curriculum.

The implementation of these new experimental tools in the process of acquisition, processing, analysis and interpretation of data in Physics Education resulted in a major qualitative leap in didactic efficiency. Thus, the defining physical quantities for a studied phenomenon can be monitored in real time. Also, the reading of the experimental data value is done quickly, with a very good precision. The experimental data stream can be stored locally or on a cloud server. Another very important aspect resides in the fact that, during a class

hour, an extended time interval is provided for the interpretation of experimental data.

In the pilot classes where we tested these didactic tools, we noticed a full active involvement of the students. We have thus verified the fact that such a methodology relaunches, among students, curiosity for the study of Physics and, in general, of Sciences. Creative thinking was consistently stimulated and constructive communication skills at the group level improved remarkably. Both digital skills and interdisciplinary Physics-ICT-Informatics skills have been developed. Students have achieved an important step in the study and assimilation of modern methods of scientific investigation. This new type of approach to teaching Physics, through experimental methods centered on Arduino development boards and sensors, facilitates the focus on the interpretation of the studied physical phenomena, provides real-time feedback from the students, therefore leads to a particularly efficient management of the time allocated to the class course.

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REFERENCES

- Aman, A., Ilham, I., Anugraha, N., Harwing, H., and Iskandar, A. (2023, May). Analysis of output monitoring system and data recording on solar panels based on ESP32. In *AIP Conference Proceedings* (Vol. 2704, No. 1). AIP Publishing.
- Buachoom, A., Thedsakhulwong, A., and Wuttiptom, S. (2019, November). An Arduino board with ultrasonic sensor investigation of simple harmonic motion. In *Journal of Physics: Conference Series* (Vol. 1380, No. 1, p. 012098). IOP Publishing.
- Chen, H.Y., Nieh, H.M., and Ko, S.W. (2022), Acceleration Measurement Using Arduino and a Smartphone for the Motion of Objects on an Inclined Plane. *The Physics Teacher*. 60. 351-354. 10.1119/5.0038831.
- Coban, A. and Çoban, N. (2020). Using Arduino in physics experiments: determining the speed of sound in air. *Physics Education*. 55. 043005. 10.1088/1361-6552/ab94d6.
- Çoban, A., and Salar, R. (2023). Analyzing Position, Velocity and Acceleration Graphs using Arduino. *Jurnal Pendidikan Fisika Indonesia*. 19(1), 36-46.
- Desnanjaya, I.G.M.N., Ariana, A.A.G.B., Nugraha, I.M.A., W., I.A.G., and Sumaharja, I.M.U. (2022). Room Monitoring uses ESP-12E based DHT22 and BH1750. *Sensors*. 3. 205-211. 10.18196/jrc.v3i2.11023.
- El Hadi, M., Ouariach, A., Essaadaoui, R., El Moussaouy, A., and Mommadi, O. (2021). RC time constant measurement using an INA219 sensor: creating an alternative, flexible, low-cost configuration that provides benefits for students and schools. *Physics Education*. 56(4), 045015.
- Hachmi, A., El Hadi, M., Essaadaoui, R., Mommadi, O., Ouariach, A., and El Moussaouy, A. (2022). Development of an educational device, based on

- Arduino, to facilitate the understanding of light diffraction. *Physics Education*. 57(4), 045032.
- Heo, G. and Jung, J. (2018). Arduino Compatible Modular Kit Design for Educational Purpose. *Journal of the Korea Institute of Information and Communication Engineering*. 22. 1371-1378. 10.6109/JKIICE.2018.22.10.1371.
- Houssem Eddine, D., Laallam, F. Z., Seggar, M., and Ayachi Amar, C. (2019). Implementation of an Energy monitoring System based on Arduino. *Proceedings of Artificial Intelligence and Its Applications*
- Kotseva, I., Gaydarova, M., Angelov, K., and Hoxha, F. (2019). Physics experiments and demonstrations based on Arduino. *AIP Conference Proceedings*. 2075. 180020. 10.1063/1.5091417.
- Mabrouki, J., Azrou, M., Dhiba, D., Farhaoui, Y., and El Hajjaji, S. (2021). IoT-based data logger for weather monitoring using arduino-based wireless sensor networks with remote graphical application and alerts. *Big Data Mining and Analytics*. 4(1), 25-32.
- Moya, A.A. (2018). An Arduino experiment to study free fall at schools. *Physics Education*. 53. 055020. 10.1088/1361-6552/aad4c6.
- Naing, Z. Z., Nyo, T. T., and Htoo, H. H. (2020). Data acquisition of solar radiation and ultra-violet (uv) Intensity. vol. XVIII. (2), 3-9.
- Nurjannah, I., Harijanto, A., and Supriadi, B. (2017). Sound Intensity Measuring Instrument based on Arduino Board with Data Logger System. *International Journal of Advanced Engineering Research and Science (IJAERS)*. <https://dx.doi.org/10.22161/ijaers.4.9.7>
- Organtini, G. (2018). Arduino as a tool for physics experiments. *Journal of Physics: Conference Series*. 1076. 012026. 10.1088/1742-6596/1076/1/012026.
- Sari, U. and Kirindi, T. (2019). Using Arduino in Physics Teaching: Arduino-based Physics Experiment to Study Temperature Dependence of Electrical Resistance. *Journal of Computer and Education Research*. 7. 698-710. 10.18009/jcer.579362.
- Shaari, S., Rahman, F. and Berahim, C. (2021). The Development of Arduino based Educational Kit: Traffic Light Prototype to Increase the User Basic Knowledge on Writing Simple Arduino Programming Code. *International Journal of Innovation and Industrial Revolution*. 3. 27-35. 10.35631/IJIREV.36003.
- Shoaib, M., Iqbal, A. M., and Imran, M. A. (2021). Measurement of Acceleration Due to Gravity Using Arduino and Ultrasonic Sensor. *Journal of Sensor Technology*. 11(4), 55-63.
- Singh, R., Singh, A., and Singhal, S. (2022). Physics experiments using Arduino: determination of the air quality index. *Physics Education*. 57. 025013. 10.1088/1361-6552/ac3d22.
- Voudoukis, N. (2017). Inverse Square Law for Light and Radiation: a Unifying Educational Approach. *European Journal of Engineering Research and Science*. 2. 10.24018/ejers.2017.2.11.517
- Zhmud, V., Kondratiev, N.O., Kuznetsov, K.A., Trubin, V.G., and Dimitrov, L. (2018). Application of Ultrasonic Sensor for Measuring Distances in Robotics. *Journal of Physics. Conference Series*. 1015. 032189. 10.1088/1742-6596/1015/3/032189