Experimental set–ups using microcontrollers and sensors realized by students to be used in Physics lessons

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Abstract. Due to the rapid pace of development of new technologies, technology can be a hopeful ally in many areas, including education. By using new progress science classes can thus be more attractive. Experiments with classic and outdated devices are not exciting for students but can now be replaced by modern devices based on sensors, actuators and microcontrollers. The paper describes how can be find solutions for experimental physics devices using in vocational education sensors, microcontrollers, actuators, etc. New technologies into the learning process can be a factor of inspiration and motivation for students embrace a career in STEM.

1. Introduction

Research in the education sciences has led to the creation of new strategies and materials that cover the students' needs and can help to overcome some learning difficulties. Robotic and mechanical applications are rapidly developing areas, in the working environments but also in education. Through robotics, the newest discoveries in the area of engineering and science can be studied by students in schools. [1]

Educational robotics can be integrated in physics lessons as tools for modeling knowledge because it sustains the design of a model that can be tested in a physical environment. Educational robotics allows the exploration, design, modeling, construction and testing of the concepts of the basic knowledge (movement, force, traction ...), but also more complex and realistic systems for what is necessary to combine different concepts and methodologies from different fields of study [2].

For a robot to be functional, it must embed different constructive elements. Thus, to integrate it into the environment and to interact with environmental elements, the robot needs sense organs, i.e. sensors and actuators, "muscles". To control all these elements, the robot needs a control center, the "brain", the microcontroller. Therefore, robotics activities must begin with the study of sensors, actuators and microcontroller [3]

Traditionally school does not provide such modern elements in the science laboratories (sensors, actuators, microcontrollers, etc.) radialional laboratories are equipped with different digital and analogical devices (multimeter, ammeter, voltmeter, etc.), which are used only for direct reading of physical quantities. To investigate the mode of operation, the construction of these devices and thus to animate as much as possible the lessons, the school should equip its laboratories with teaching materials based on the latest technologies and nanotechnologies.

In the new stipulations for equipping science laboratories, the Ministry of Education does not intend to provide such modern teaching materials to schools, however, a teacher who wants to keep up with the technological development market could purchase, within a reasonable amount, a small kit of
robotics, which contains the main elements to realize the first steps towards an education for the new technologies. An example of such a kit is the one based on the Arduino development board and the Arduino IDE development environment. The advantage of this development environment is that it includes a very wide range of sensors and actuators compatible with the Arduino development board and also the use of a programming language accessible to the high school level.

2. Formal and informal education, alternatives to education for new technologies

A way to achieve education for new technologies is to combine formal education, providing systematic knowledge of the core disciplines, with a percentage of informal education, which is especially effective for broadening horizons, encouraging curiosity and active learning. The central role in the informal education can be played by the robotics and mechatronics clubs, and the central role in achieving a formal education for the new technologies can be played by the optional curriculums (in Romania, the National Curriculum offers the possibility for teachers to draw optional educational programs, called curriculum at the decision of the school, which aim to achieve an additional path for developing the specific skills of a particular field). Club activities and optional educational programs reinforce, support and supplement science and technology studies in schools. With the help of formal and informal education, state-of-the-art educational technologies and strategies can be implemented to involve students in various interactive learning activities.

At the Technological High School "Saint John de La Salle" from Pildesti, Neamț, an informal education mode centered on the topics of new technologies started in the 2017-2018 school year, in the form of a robotics club, the NanoTechFun club, and from the 2018-2019 school year a local development curriculum (CDL) was implemented as a way of conducting formal education for new technologies.

The proposal of the "Operating and programming sensors, actuators and robots" CDL is the result of interpreting a survey, based on a questionnaire, on the needs of students in order to be easier to integrate them into the jobmarket in the future qualification field. Following the analysis of the questionnaires, it was found the need to introduce topics meant to prepare the students, theoretically and practically, for a possible career in the field of sensors and actuators, automatics and robots or for the in-depth studies at university level, as well as the need for interdisciplinarity, correlating the contents of the modules from the specialized training with the contents from the Physics, Mathematics and Informatics.

The purposes of the local development curriculum are: raising the levels of achieving the competences proposed by the differentiated curriculum necessary for the professional insertion by acquiring some theoretical knowledge and practical skills of programming and integrating the sensors and actuators in the realization of robots; broadening the occupational domain, but also deepening key competences, along with personal and social competences such as communication, teamwork, critical thinking, responsibility, creativity and entrepreneurship.

The CDL is based on the following contents: i) Sensory elements. Measurement processes. Types of sensors. Sensor physics. Types of signal. Numerical processing of signals; ii) Elements of actuation and automation. Types of actuators. Engines. Types of orders; iii) Amplifiers and converters. Voltage amplifiers adapted to sensors and actuators. Current amplifiers adapted to sensors and actuators. Analog-to-digital converters. Digital-to-analog converters; iv) Microcontrollers. General information. Types of signals. Microbit, Arduino; v) Programming elements. Programs. Artificial intelligence; vi) Elements of design - implementation of robotic solutions.

The activities of the NanoTechFun robotics club are based on the development environment, together with the Arduino development board, sensors compatible with the Arduino development environment, the Lego Mindstorms EV3 kit and the BBC Micro: Bit microcontroller by which we familiarize students in the primary cycle with the concept of sensor, microcontroller, robotics and robot programming mode.

At the moment, the club is focusing on the use of sensors and actuators in various projects that will help the teachers in the field of science in making lessons attractive and fun for their students.

As a physics teacher, I always look for new ways of teaching physics to help students love this subject. By combining these two forms of education (the CDL and the robotics club) I managed to get students to see physics from a different angle, not just theory and problems. Thus, using the principles...
of physics and the notions of sensor, actuator, microcontroller studied within the CDL, we managed to create devices that helped us to animate the physics lessons, to understand the studied physical phenomena based on the experiment, not just imagining them from the theory.

In the 2018-2019 school year we managed to develop devices that would cover all the contents of physics studied at the high school level: mechanics, thermodynamics, electricity and optics. The experimental installations designed are aimed at measuring or highlighting the observable physical phenomena within the compulsory experiments in the school syllabus.

3. Examples of experimental set-ups

3.1. Monitoring of atmospheric conditions with Arduino Nano and BME280 sensor

The environment we live in is extremely important to our health. Humidity, temperature and atmospheric pressure can influence our health. To be able to control them we need measurements tools. We are all familiar with thermometers, but hygrometers for measuring humidity and barometers for measuring pressure are a little rarer. This means that, in order to be able to determine the environmental parameters, we would have to use three measuring instruments. Because the versatility of the new technologies, we can build a single device able to record all these parameters at the same time using a single sensor and microcontroller [4].

The device (figure 1 experimental device layout and figure 2 wiring diagram), programmed in the Arduino IDE C / C ++, is capable of analyzing various external factors such as barometric pressure, humidity, altitude, and temperature, using an Arduino Nano board, the BME 280 sensor in the SparkFunQwiic module and converting them into digital signals that will be saved on a card using the MicroSD Card Slot module. Using this device, one can understand how the atmospheric pressure varies with air and altitude.

![Figure 1: Experimental device layout](image1)

![Figure 2: Wiring diagram](image2)

The BME280 sensor measures: temperature from -40 °C to 85 °C; humidity, 0-100% RH; the pressure from 30,000 Pa to 110,000 Pa (Absolute Accuracy of 100 Pa); altitude, from 0 km to 9.2 km (relative accuracy between 1 m and 2 m) and is powered at 3.3V. [5]

MicroSD Card Slot Module is a MicroSD-compatible adapter that can be used to write and read MicroSD cards through the ISP interface.

In order to check the decrease of pressure with altitude, measurements were made in the tower of the church in Gheraesti, Neamt County (Table 1) and on the peak of Cozla Mountain in Piatra Neamt (Table 2).
Table 1: Tower of the church in Gheraes

| Nr | Humidity (%) | Pressure (Pa) | Altit. (m) | Temp. (°C) |
|----|--------------|--------------|-----------|------------|
| 1  | 54.87        | 98817.29     | 224       | 26.62      |
| 2  | 55.50        | 98816.88     | 224       | 26.54      |
| 3  | 55.86        | 98816.97     | 224       | 26.35      |

Table 2: Cozla Mountain in Piatra Neamt

| Nr | Humidity (%) | Pressure (Pa) | Altit. (m) | Temp. (°C) |
|----|--------------|--------------|-----------|------------|
| 1  | 55.80        | 94745.99     | 582.77    | 27.12      |
| 2  | 54.17        | 94740.50     | 582.73    | 27.08      |
| 3  | 55.06        | 94742.64     | 582.59    | 27.11      |

Since the atmospheric pressure is usually expressed in mm Hg, we obtain the following pressure values:
- in Gheraes: \( P = 99532.22 / 133.28 = 746.79 \) mmHg;
- at the foot of Cozla Mountain: \( P = 98817.29 / 133.28 = 737.97 \) mmHg
- on Cozla Mountain: \( P = 94740.50 / 133.28 = 710.83 \) mmHg

3.2. Determining the speed of sound using an ultrasonic sensor and the Arduino controller

Air molecules tend to move more easily through hot and humid environments due to the fact that under these conditions their internal energy increases [6]. As the speed of sound depends on how the air pressure changes when the molecules collide with each other (creating areas of compression, but also areas with more rarefied air), the elasticity of the molecules becomes an important factor. That is the reason why, during hot and humid days, the sound travels faster than on a cold, dry day, when the air molecules do not oscillate as easily as in the first case. [7]

To determine the speed of sound in different environments, we need a sensor that reads the air temperature. The cheapest option is the DHT11 temperature and humidity sensor. [8]

HC-SR04 sensor it is compatible with Arduino and has several advantages over analogue sensor sensors: it requires only digital I/O pins, has higher immunity to noise. It has a precision of 3mm and measures at an angle of 15°. It is easy to use and consumes little energy, the main disadvantage being the relatively small measuring distance: 2 cm - 4 m. [9]

DHT11 is a high-performance temperature and humidity sensor, ensuring high reliability and excellent stability. Humidity detection range: 20 - 90%RH; Humidity measurement accuracy: ± 5% RH; temperature measuring range: 0 - 60 °C; accuracy of temperature measurement: ± 2 °C; supply voltage: between 3.3 and 5 V. [10]

In Figure 3 the experimental device layout is shown, while figure 4 shows the wiring diagram.

Figure 3: Experimental device layout

Figure 4: Wiring diagram

The sound speed, calculated according to temperature, at different times of the day is displayed from the Arduino program monitor. Table 3 is show the data at 6 a.m, table 4 is show the data at 10 a.m, table 5 is show the data at 1 a.m and table 6 is show the data at 8 a.m.
It is noted that the first readings are irrelevant because the calibration of the sensors takes place. Plotting the graph of the temperature versus the speed of sound (Figure 5), the students noticed that indeed the speed of sound increases with increasing of the temperatures.

![The grafic of temperature versus the speed of sound](image)

**Figure 5:** The grafic of temperature versus the speed of sound

### 3.3. Waveform generator

Electromagnetic waves represent periodic variations in time and space of the electromagnetic field. They can be generated by specific electronic circuits, which represent open oscillating systems and that propagate in space at the speed of light. They are characterized by a series of parameters such as: intensity, polarization, wavelength etc. [11]

The wave generator is a very useful tool, especially when we are considering testing a circuit's response to a particular signal. Our device contains: Arduino Nano board, LCD display (16x2), 5-pin rotor, 25 resistors of 10KΩ, LM358 integrated circuit, MT3608 DC-DC Step Up Module, a 1μF capacitor, potentiometer, digital oscilloscope DSO138. To get the waves it will change the type of current in the DSO138 digital oscilloscope, change the oscilloscope voltage, decrease and increase the frequency with the rotor until different waveforms are obtained. [12]
LM 358 is designed for general use as an amplifier, high pass filter and low band width filter and analog signal band. It can operate from 3V to 32V DC and up to 20mA per channel.\[12\]

MT3608 DC-DC Step Up Module this module includes the 2 Amp step up (boost) MT3608 converter that can handle input voltages as low as 2V and increase power up to 28V. This includes voltage blocking, current limitation and thermal overload protection. It is a step-up mode, at which the output voltage is greater than the input voltage. [12]

Figure 6 shows the layout of the device, and Figure 7 shows the electrical design of the experimental device.

![Figure 6: Waveform generator device layout](image1)

![Figure 7: Wiring diagram](image2)

To obtain different waveforms, change the current type (DC or AC) of the DSO138 digital oscilloscope, the oscilloscope voltage and decrease or increase the frequency value with the rotor. The Table 7 shows different waveforms obtained by students.

| Number | The form of the current | Tension | Frequency | Waveform-drawing |
|--------|------------------------|---------|-----------|------------------|
| 1      | AC                     | 0.1V    | 500 kHz   |                  |
| 2      | DC                     | 1V      | 300 kHz   |                  |
| 3      | AC                     | 10 mV   | 700 kHz   |                  |
| 4      | DC                     | 10 mV   | 700 kHz   |                  |
| 5      | AC                     | 1V      | 700 kHz   |                  |

3.4. Speed detector
All bodies move, and movement is an intrinsic property of matter. But not all bodies motions are the same. Some move faster, others move more slowly. In order to distinguish between the different movements of the bodies, the notion of speed is introduced, noted with the letter v. Speed is the physical size attached to the property of the bodies to be in motion. Speed is the physical size equal to the ratio of space to time. An example of a modern device for determining the speed of a body is the „Speed detector”. [13]
The device (Figure 8) is made up of 2 sensors and an Arduino Uno board. The sensors used are designed and built on the principle of the frequency divider, having as a principle the variation of a photoresistance. The photoresistance ranges from 4 to 8k Ohm in a lighted environment, reaching a variation of 180k Ohm when the environment is no longer lighted. The analogue value is read from the main node (voltage variation on the photoresistance) and when an object passes over the photoresistance, it reaches a very high value, which causes a high voltage drop. This drop in tension marks the fact that an object has passed through its radius.

![Speed detector device layout](image)

**Figure 8**: Speed detector device layout
The sensor layout consist in potentiometer that is designed to adjust the variation of photoresistance in the measuring system (values between 0 Ohm and 10.10 ohm). The two photoresistors detect the time \( t_1 \) and \( t_2 \) and calculate the speed of the object while maintaining the distance between the sensors.

The device can be used to check the speed calculation formula, \( v = \frac{d}{\Delta t} \). The data read from the sensors is shown in Table 8.

| Nr | \( L \) (m) | \( t_1 \) (s) | \( t_2 \) (s) | \( \Delta t \) (s) | \( v_{\text{sensor}} \) (m/s) |
|---|---|---|---|---|---|
| 1 | 0.185 | 1.086 | 1.511 | 0.425 | 0.44 |
| 2 | 0.185 | 1.882 | 2.712 | 0.83 | 0.22 |
| 3 | 0.185 | 1.523 | 2.212 | 0.689 | 0.27 |

Data recording in this case, is essential to be able to demonstrate to students that the speed at which an object is moving is influenced by time. Students may notice that if the travel time is short, the speed at which an object moves between two points is high and if we increase the distance travel time the speed decreases.

To verify the speed values, the following calculations were made:

\[
\begin{align*}
  v_1 &= \frac{0.185}{0.425} = 0.438 \text{ m/s} \\
  v_2 &= \frac{0.185}{0.830} = 0.228 \text{ m/s} \\
  v_3 &= \frac{0.185}{0.689} = 0.268 \text{ m/s}
\end{align*}
\]

4. Feedback from formal and informal activities
The activities of the robotics club and the CDL managed to capture the attention of all students in the school. After completing the CDL "Operation and programming of sensors, actuators and robots", the students managed to learn the main physical phenomena underlying the functioning of the different sensors compatible with the Arduino board and at the same time became familiar with the main concepts of designing and programming a robot based on a microcontroller and a sensor / actuator. As proof we have the testimonies given by the students after completing the curriculum: "During the CDL classes, we have managed to accumulate a lot of knowledge in the field of technology and robotics. We used..."
different sensors, learned the physical principle that underlies their operation and made assemblies that helped us to understand how the sensors, actuators, and microcontrollers work. I learned what a microcontroller means and we made projects that help us in our daily life” (Carla, 17 years old); "In the CDL I learned that Arduino is a development board based on a microprocessor and we learned how to use sensors in everyday life", (Rita 17 years); "At this CDL we learned how to use sensors, actuators, and microcontrollers in the design of robots, as well as how to operate the sensors. The module was a very interesting one where I had the opportunity to familiarize myself with certain basic concepts that will certainly be used in my college studies” (Lucian, 17 years old).

The members of the club have confessed that they particularly appreciate the activities that develop both their imagination, creativity and the desire to study in-depth the disciplines related to robotics. A 10th grade student confesses "... I have been in the club for two years and I have no regrets, this club helped me discover my passion. In the last school year, I had pleasant experiences. Together with the other members, we designed and developed activities for school competitions. The projects were well chosen and all the club members had something to do during the meetings.” A 9th grade student states that: "... at the club is a pleasant atmosphere, we help each other, we experiment, dismantle, discuss, advise and work". The students of the 11th grade confessed: "In the club, I learned many new things, such as the main steps in creating a project with the help of Arduino", "I liked the robotics club, I felt good and I learned some interesting things. We went to contests with great emotions, but all these extra efforts deserved the satisfaction of the happy ending”. Feedback was given after the completion of each project and at the end of each school year.

School results are also a benchmark in terms of the club’s impact on club members. Analyzing the general average results of the members of the robotics club before joining the club and after joining, an increase in the level of general training was observed: the students in the 10th grade in the 2018-2019 school year registered an increase compared to the 9th grade with an average of 0.65 points, (7.64 - 8.39; 8.73 - 9.26; 8.67 - 9.34; 9.87 - 9.89); the students of the 11th grade - in the 2018 - 2019 school year also registered increases of the general average compared to the 9th and 10th grades with an average of 0.53 points (9.70 - 10 - 10; 9.55 - 9.60 - 9.68; 9.38 - 9.42 - 9.71; 8.91 - 9.36 - 9.68); the students in the 12th grade in the 2018-2019 school year registered increases of the general average compared to the 9th, 10th and 11th grades with an average of 0.36 points (8.42 - 8.26 - 8.64 - 8.95; 9.15 - 9.23 - 9.27 - 9.56; 9.31 - 9.41 - 9.54 - 9.56).

5. Conclusions
Formal education and informal education under the two forms organized within the Technological High School "Saint John of La Salle", the curriculum in local development and the robotics club represented and represents an important asset in the intellectual and formal development of students.

By working with devices based on sensors, microcontrollers, teachers and students can find modern ways of studying physics effect, laws, phenomena, and can thus foster the student interest in STEM. Sensors, actuators and microcontrollers have a great impact in today's society such as robotics, mechatronics, mobile science and smart home technologies. By introducing in classroom practice the traditional passive learning model can be replaced by active learning teachers taking the role of mentors, innovators, counselors or coaches while the students the role of designers of desired tool in studying a peculiar physics lesson.

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