Arduino Setup Used as Didactic Tool for the Dynamic Study of Torsion

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Abstract

The paper presents investigations of the dynamic study for the torsion of a wire by means of an experimental setup based on an Arduino micro-controller device. This method turns out to be very efficient, while the experimental results are in very good agreement with the theoretical calculations and with other investigation methods. Moreover, the Arduino based data acquisition setup is cost effective, easy to install and operate and the software is free (also open source). This approach represents an integration of new technologies in physics education, offering users applicable modern alternatives in didactic physics laboratory.

Keywords: Arduino, Dynamic study of the torsion, Physics education

1 Introduction

Theoretical approach [Cheche and Barna, 2006; Cheche and Chang, 2005], modelling-based learning activities [Marciuc et al, 2016; Grigore et al, 2013; Marciuc and Miron, 2018; Grigore et al, 2015; Lazar 2019] and experimental data [Pantazi et al, 2019; Dinu et al, 2019; Barna et al, 2004; Gatin et al, 2000a; Gatin et al, 2000b] play a crucial role in understanding and learning the concepts of physics. There is large diversity of results through scientific studies in traditional face-to-face or in blended educational frameworks [Lazar et al, 2020]. Investigation Based Learning (IBL) approaches lead to a better understanding of the physics phenomena and of the used concepts [Galan et al, 2017] that can be used in all teaching and learning contexts.

In this respect, experimental devices adequate to the needs of the proposed investigation, that provide a high level of precision, while being explicit and modern, are very useful. Projecting an experimental setup, including the means of measuring and data analysis can develop students' competences in a high degree and help them to better understand the theoretical abstract notions and how they fit in the daily life, to make connexions between concepts, between theoretical models and real phenomena [Wong et al, 2015; Dauphin and Bouquet, 2018; Liang et al, 2017].

Using new technologies in physics laboratories is highly necessary from many points of view. Firstly, it helps to increase the precision of the measurements and ease the calculus part, graphic construction, while leading to more accurate results with lower error level. In many situations, use of new technologies is a cheaper procedure to update the physics laboratories using electronic devices instead of the old ones.

The authors already tackled the dynamic study of torsion by means of video analysis procedure with tracker software [Chiriacescu et al, 2020a] and the present paper represents another experimental approach while using an Arduino device.

2 Experimental setup and methodology

For the dynamic study of torsion, we used an experimental device (Fig. 1) made up by two main parts: the mechanical part (a torsion pendulum) identical with that one used in [Chiriacescu et al, 2020a] and the electronic part for measurements (Arduino device and required auxiliaries).

The main mechanical part of the setup consists of a steel-string vertically suspended on a fixed stand. On the wire, a rod is attached horizontally and symmetrical with respect to the vertical axis. Two identical cylinders are attached to the rod. The cylinders can slide along the rod (the small grooves allow positioning the cylinders symmetrical on both sides of the rod). The device has also a circular protractor that allows the measurement of the deviation angles from the equilibrium position.

The main goal of the experimental setup is to determine the torsion constant C of the wire following the relation [Chiriacescu et al, 2020a; Ciucu et al, 2009; French, 1971; Hristev, 1984]:

$$T_0 = 2\pi\sqrt{\frac{I_0}{C}} \quad [1]$$

where T_0 is the period of oscillation of the rod and I_0 is its moment of inertia about the axis passing through the center.

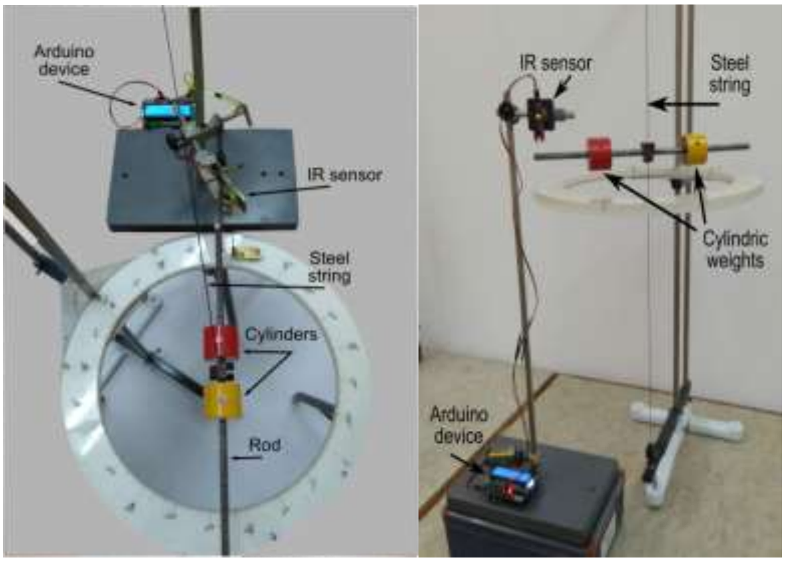


Fig. 1. Details of the Experimental Device.

The values for the parameters of the experimental setup are summarized below [Chiriacescu et al, 2020a; Ciucu et al, 2009]:

- length of the rod: $l = 358 \pm 1\ mm$;
- mass of the rod: $m_0 = 150 \pm 0.5\ g$;
- mass of a cylinder: $m_c = 350 \pm 1\ g$;
- length of the cylinder: $l_c = 35 \pm 1\ mm$;
- outer radius of the cylinder: $R = 20 \pm 0.05\ mm$;

- inner radius of the cylinder: $r = 3.95 \pm 0.05\ mm$;

The above values are used to estimate the following main physical quantities that are later employed in the data processing [Chiriacescu et al, 2020a; Ciucu et al, 2009]:

- moment of inertia of the rod about the axis passing through its center:

$$I_0 = \frac{1}{2} m_0 l^2 = 1.602 \cdot 10^{-3}\ kg \cdot m^2 \qquad [2]$$

- moment of inertia of a cylinder relative to its center

$$I_c = \frac{1}{4} m_c \left(r^2 + R^2 + \frac{1}{3} l_c^2 \right) = 0.072 \cdot 10^{-3}\ kg \cdot m^2 \qquad [3]$$

- moment of inertia of the ensemble of the rod and the cylinders situated with their centers situated at distance d from the wire (which coincides with the center of the rod):

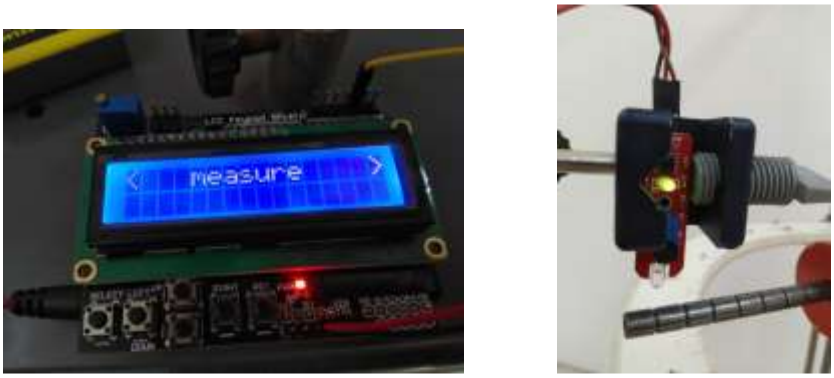
$$I = I_0 + 2I_c + 2m_c d^2 \qquad [4]$$

The moment of inertia of the ensemble has a constant part (Z) which is calculated elsewhere [Chiriacescu et al, 2020a]:

$$Z = I_0 + 2I_c = 1.746 \cdot 10^{-3}\ kg \cdot m^2 \qquad [5]$$

From the above considerations, one can notice that the most important part is to measure the periods of oscillation, that is achieved by means of the Arduino component and it is the main objective of the present paper.

The electronic device used to measure the pendulum oscillation periods is made of an infrared sensor and an Arduino micro-controller [https://www.arduino.cc/en/Guide/HomePage]. It is an open-source platform consisting of a motherboard connected with several peripheral devices, sensors and output devices. In this case, the device has an LCD screen attached and also a control panel (Fig. 2a). The employed sensor is based on a TSOP (Thin Small Outline Package) detector (Fig. 2b).



a) b)

Fig.2. Electronic device – details: a) Arduino device with attached LCD screen and control panel; b) IR sensor based on a TSOP detector.

The operating principle is shown in Fig. 3. A LED (Light Emitting Diode) emits an infrared (IR) beam towards the end of the rod that reflects the ray. The reflected fascicle is received by the optical sensor, the TSOP device that firstly transforms it to an electrical signal, which it is amplified and sent to the Arduino device. The sensor detects only a certain IR radiation; in this way, the measurements are not influenced by visible light from the Sun or other environmental lights [Chiriacescu et al, 2020b].

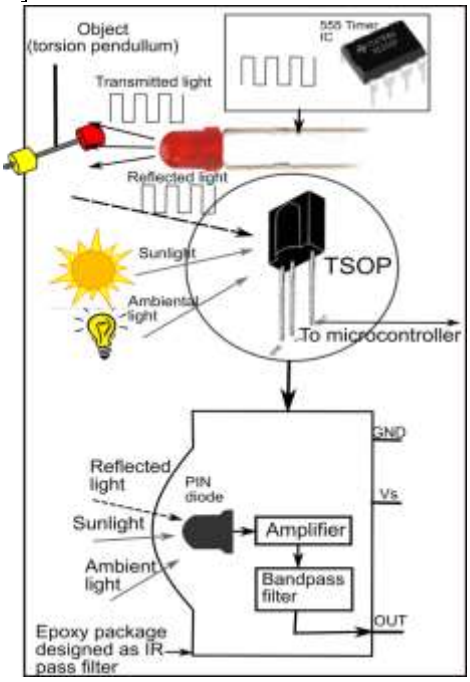


Fig. 3. The experimental sensor setup and the Arduino device for measuring the oscillation period.

The sensor points towards the end of the rod and it's activated by the passing of the metallic rod in its vicinity. In this way, two periods of time can be determined: the time that the rod is in the range of the sensor and the time that the rod is outside the range of the sensor when the detector doesn't read anything. The sum of the two periods of time represents the pendulum's oscillation period. The collected data is then sent to a computer where it is registered, processed and interpreted. In order to start the experiment, the two cylinders are symmetrically fixed by the oscillation center in different positions along the metallic rod [Chiriacescu et al, 2020a]. The cylinders are moved successively with steps of 1cm, starting from the extremity of the rod towards the center. The rod is then taken out of the equilibrium position. In the wire is therefore induced a torsion momentum that will try to bring back the rod in the equilibrium position. In this way, we manage to obtain small oscillations of the rod (the oscillation angle should not be greater than 5 degrees, in order to maintain the conditions of small oscillations). Moreover, the oscillations should be just in the horizontal plane. By employing the control panel, one can start registering the oscillation period. The measurement should be made for a large number of oscillations, in order to ensure an increased precision of the acquired data. A reference measurement of the oscillation period is made in absence of the cylinders, considering only the metallic rod.

3 Results and discussions

We used the experimental setup to determine the oscillation period of the rod with cylinders symmetrically situated at different distances from the wire. The dependence of the oscillation period on the parameters of the experimental setup is given by [Chiriacescu et al, 2020a]:

$$T^2 = \frac{4\pi^2}{C}\left(Z + 2m_c d^2\right) \quad [6]$$

It follows that the dependence of T^2 on d^2 is linear and, from the parameters of the graph, we can determine the torsion constant C of the wire. The experimental data are in very good agreement with the theoretical calculations and the linear dependence is depicted in Figure 4.

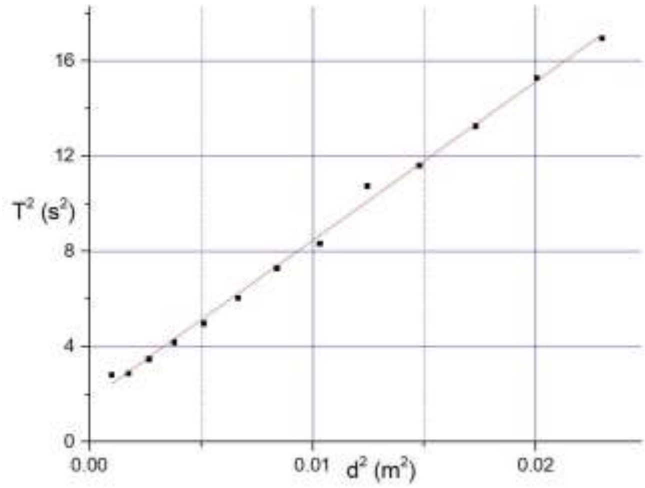


Fig. 4. The plot of T^2 versus d^2 obtained from the processed experimental data

The linear fit of the curve in Fig. 4 has the slope $a = 667.685 \pm 11.006 \frac{s^2}{m^2}$ and the intercept $b = 1.788 \pm 0.132\, s^2$.

From equation [6], by using the slope and the mass of the cylinder, we get the torsion constant of the wire $C_{graph} = 4.13 \cdot 10^{-2}\ N \cdot m / rad$.

After the constant G_{graph} is determined from the slope, one can use the intercept in equation [6] and also calculate $Z_{graph} = I_0 + 2I_c = 1.872 \cdot 10^{-3}\ kg \cdot m^2$, (the obtained value is quite similar to the theoretical value).

In order to further check the validity of our measurement method, we also calculated the value of $Z_{\exp}$ by using the method described in [Chiriacescu et al, 2020a]: if T_1 is the oscillation period for cylinders situated at distance d_1 from the center of the rod and T_2 is the oscillation period for cylinders situated at distance d_2, then the value of $Z_{\exp}$ is given by:

$$Z_{\exp} = 2m_c \frac{T_1^2 d_2^2 - T_2^2 d_1^2}{T_2^2 - T_1^2} \quad [7]$$

From the data set, we selected $d_1 = 5.15\, cm$ with $T_1 = 1.871\, s$ and $d_2 = 13.15\, cm$ with $T_2 = 13.271\, s$ and we then calculated $Z_{\exp} = 1.815 \cdot 10^{-3}\ kg \cdot m^2$.

Using $Z_{\exp}$, we determined the moment of inertia of the rod, obtaining $I_{0\exp} = 1.634 \cdot 10^{-3}\ kg \cdot m^2$, value very close to the calculated one. With $I_{0\exp}$ and with the oscillation period of the rod without cylinders in equation [1], we obtained again the torsion constant of the wire, $C_{\exp} = 4.14 \cdot 10^{-2}\ N \cdot m / rad$.

The resulting values obtained in this paper are in very good agreement with those in [Chiriacescu et al, 2020a], validating both of the experimental methods that we used to determine the torsion constant of the wire.

4 Conclusions

The presented physical method has multiple advantages. The most important one is related to an increase in the precision of the measurements (we pointed out the accuracy of the obtained experimental data in the paper). Implementing the new technologies in the physics laboratories can open new perspectives of the experimental techniques. The Arduino device and its auxiliaries prove to be an excellent opportunity for updating the lab technology while maintaining a low budget. The software used is free of charge and open-source with a great number of users and programmers that leads to frequent updates and helpful tutorials. There is also a big pool of free documentation on the Internet, which eases the implementation of these experimental methods, even for less experimented students. From the students' point of view, the present approach clearly increases the experimental aptitudes in projecting an experimental setup, boosting the IT and technological competences, while additionally rising critical thinking ability.

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