Development of a "Small Contractions" Sensor for Practical Work in Biology Using 3D Printing Technology

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Abstract—This article presents the development of a "small contraction" sensor fabricated using 3D printing and intended for practical works of biology; with the aim to replace the traditionally used system. This fabricated sensor is then integrated into a Computer Assisted Experiment (CAE) environment. CAE is a teaching technology that allows the students to carry out the acquisition and the processing of their data on computer (saving, adding comments, amplification…). The combination of these two technologies (CAE and 3D printing) has made it possible to equip low-cost multipurpose labs requiring minimal maintenance and where the work space is standardized. The result of a survey conducted with the students at the end of the lab sessions shows that 79.1% of them prefer the use of the new system, given the advantages it offers in terms of better understanding of the practical works objectives, time saving and the data processing functionalities it provides.

Keywords—computer assisted experiment, 3D printing technology, practical works in biology

1 Introduction

The practical activities in biology are designed to help students acquire basic scientific skills and improve their performance and achievement. practical work (PW) helps students practicing an experimental approach, develop critical thinking, develop hypotheses, design experiments and interpret results [1], [2][3][4].

In the Moroccan higher education system, these experimental activities undergo several obstacles as the massive retirements of professors and technical staff, poor recruitment of new professors and technicians, massive student enrolment and deterioration and poor maintenance of equipment and infrastructure.

In addition to the structural problems mentioned above, there are also technical problems. Indeed, most of these PWs are traditionally realized using an outdated equipment. Animal Physiology practical works for example depend on a mechanical mechanism that serves for data collection. This mechanism is made of a lever articulated around an axis. One of lever's ends is attached by a wire to the studied organ, the other one is equipped with a pen which registers the organ movement on a paper wrapped around a rotating cylinder.

This system has several disadvantages, namely: i) problems of initial adjustment of the system in order to reduce the friction of the pen on the cylinder, ii) the system does not offer an amplification of the signal resulting from the movements of the organ.

As a result of these problems, several experiments have been withdrawn from the animal physiology courses at the Faculty of Sciences of Rabat (FSR) in recent years, which has negatively impacted the scientific level of the laureates.

In this context, a collaboration between two teams from Biology and Physics departments at the Faculty of Sciences of Rabat has been initiated. The objective of this collaboration was to develop an acquisition system of small biological movements that will help overcome the limitations of the current system. This system must be user-friendly, allow the amplification of the obtained signals and be based on new technologies.

For this purpose, two technologies were used, which are the Computer Assisted experiment CAE and 3D printing.

CAE [5]–[9], is a teaching technology that uses the computer as a teaching tool, and whose didactic advantages are associated with the real-time graphic representation of the studied phenomenon. The fact that, the real experimental action and [10] its graphic representation are represented simultaneously, is illustrated by the metaphor of « the cognitive glasses » [11]. In addition to this, it allows the presentation of multiple measurements from different sensors simultaneously rather than sequentially. This allows the student to both save time and better understand the interaction between variables.

3D printing, on the other hand, is [12], [13] widely used in teaching either (i) in the development of courses and projects that explicitly focus on 3D printing skills, or (ii) as part of courses and projects to support the teaching of other subjects, and to facilitate multi- and interdisciplinary approaches [14]–[17], usually through the use of 3D printed artefacts [18].

In our case, the combination of these two technologies to produce sensors dedicated to practical work, constitutes a new form of use of 3D printing in teaching. In this article, we are describing the development of a new sensor dedicated to the study of biological contractions of muscles. This sensor will be connected to an acquisition board and the display of the results will be done on a computer using the driver software of this board.

The outcome of a survey conducted among students showed that 79.1% of them prefer to use the developed sensor, as this solution simplifies the data processing for them while increasing the time needed for reflection, analysis, and interpretation of the results. In addition to this, professors and technical staff find that this solution offers the possibility to equip multipurpose rooms requiring minimal maintenance at a low cost and to standardize the workspace.

2 Material and method

2.1 Modelization and design

The "small contraction" sensor is a measuring instrument that can detect very small contractions of muscle in situ in its natural state of activity and / or in response to mechanical, electrical or chemical solicitations: it is intended to measure the contractions of several muscles such as:

- Heart rate in mice or frogs
- Response of striated muscles in frogs
- Intestinal or uterine muscles contractions of the rat

The 3D printed sensor is composed of two parts, the first one is the mechanical part and the second one is the electronic part. The mechanical part of the sensor consists mainly of a mechanical lever encapsulated in a box to isolate the sensor from external light, and also to make it robust enough to be used by students. The electronic part is based on a light emitting diode and a photoresistance.

Mechanical study. The contractions of muscles like the uterus or the intestine being very weak, the idea is to amplify them mechanically using a mechanical lever.

In the initial state, the lever is in mechanical balance placed on a fixed support. The lever is equipped with a reflective layer at its far end and an adjustable mass at the end near the axis.

The power ratio of the lever is given by:

$$F1 = L2.F2/L1 \qquad (1)$$

Or also according to the displacement of the ends:

$$dx1 = L2.dx2/L1 \qquad (2)$$

with:

L1 is the shorter part, L2 is the longer part, where dx1 is the displacement proportional to the force F1 applied by the muscle attached to the end A of the lever and dx2 is the distance from the reflective surface to the measuring device.

When a substance is injected, the muscle relaxes or contracts and varies the force applied to the lever.

Fig. 1. Diagram of the mechanical lever

To make the mechanical gain variable, three values of L1 are possible (5 mm-10 mm-15 mm) while for L2 only one value (80 mm), giving multiplication factors of 16, 8 and 5.33.

According to the data collected from the graphs obtained by the used system, the maximum displacement of a muscle is 5 mm. For a mechanical gain of (L2 /L1) =5.33, the maximum amplified displacement obtained is 27 mm. The lever at equilibrium is placed in the middle in order to be able to detect also the release movements of the studied muscle, so the encapsulation box is 54 mm high (see Figure 3).

Electronic circuit. The electronic part of the system consists essentially of a photoresistor and a luminous LED placed in two compartments separated by a wall (see Figure 2).

The photoresistor is placed directly under the reflecting surface which allows the measurement of the reflected light quantity. This reflected light is proportional to the distance of displacement dx2 and therefore to the amplified distance dx1.

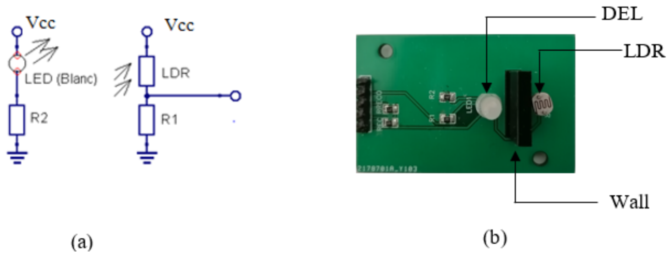


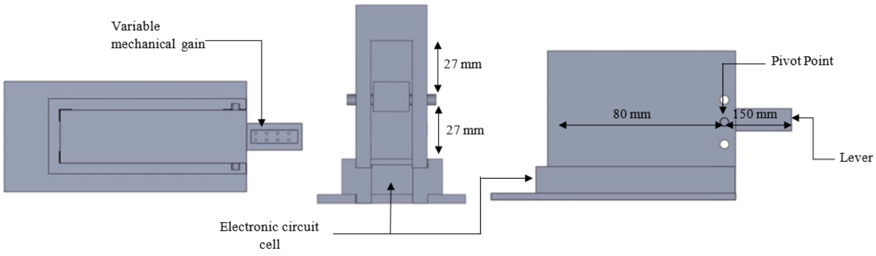
Fig. 2. (a) Schematic and (b) Picture of the electronic circuit

The sensor is then connected to a "MicroLab ExAO" acquisition board, for real-time signal acquisition. This board has four inputs, two of which are equipped with a programmable amplifier[19]. The driver software of this board offers the possibility to specify the interval of the signal to be amplified, so the continued component of the original signal is automatically subtracted and the result is then amplified, which allows to provide a high precision (see Figure 4).

3D printing. The 3D design of the sensor shown in Figure 3 is made with the Catia software. The design composed of a cell for the electronic circuit and another for the mechanical lever. To fabricate the small displacement sensor, we used the Volumic3D 3D printer based on fused deposition printing (FDM) technology. This technology uses a heated nozzle to fuse polymer filaments to form 3D objects.

The used machine is equipped with a single extruder nozzle which has a diameter of 0.3 mm, has a resolution of 25 µm, and allows to print objects with a maximum size of 290x200x300mm. To generate the Gcode, we use the Simplify3D software.

We chose this technology because it allows us to fabricate the sensor with a good quality at a very reasonable cost compared to other 3D printing technologies.



(a) (b) (c)

Fig. 3. 3D design of the sensor. (a) Top view. (b) back view. (c) side view

The most popular materials are PLA (polylactic acid) and ABS (acrylonitrile butadiene-styrene).

In our case, we used PLA, because according to [20], a comparative analysis between ABS and PLA parts produced by the FDM technique showed that, ABS filament was found to be more ductile than PLA, but the latter is stiffer and has a higher tensile strength. Thus, PLA parts behave in a more rigid manner.

The 3D printed sensor is shown in Figure 4.

(a) (b)

Fig. 4. Picture of the realized sensor, (b) picture of the acquisition board

3 Results

We will describe here a concrete comparative experiment, carried out using both the developed system and the mechanical cylinder system, in order to highlight the advantages and disadvantages of our new sensor and to verify via a questionnaire the students' opinion.

For their university curriculum, biological sciences students preparing their bachelor's degree have theoretical lectures and practical Lab courses helping them approach and understand certain physiological phenomena observed in animals and humans. In semester 4 of bachelor's degree, students study the properties of the muscular system and the contraction characteristics of different muscle types. Indeed, at this level, they become aware of the importance of vertebrate's skeletal muscles in movements genesis and the specific properties that help muscles fulfill their physiological responses, such as excitability (perceiving a stimulus and responding to it), contractility (contracting with force in the presence of appropriate stimulation), extensibility (stretching beyond their rest length) and elasticity (shortening and resuming the rest length). The theoretical lectures are complemented by an experimental work session during which the students are led to manipulate the gastrocnemius muscle of the frog and study the properties of its contraction. This practical work is done over a period of 4 hours during which the students work in pairs according to the experimental approach to define the muscular contraction properties. The objectives of the experimental work are to 1) Study the contraction of the isolated frog's gastrocnemius muscle. 2) Highlight the phenomena of muscle excitability, recruitment, summation, muscle fatigue and tetanus.

To do this, the gastrocnemius muscle is isolated in full compliance with the bioethics rules and guidelines. The muscle is then maintained in optimal conditions to keep the tissues alive for few hours, run the experiment and collect data. The muscle thus isolated is installed in suspension in a device which allows the recording of the contraction mechanics. Indeed, to limit lateral movements that may interfere with the recording, the muscle is attached on the lower side to a metal support using sewing thread. Parallelly, the muscle is attached by its upper side using a second sewing thread to a lever that carries a stylus that students fill with ink and put in contact with the recording paper placed around the recording cylinder that rotates at a predefined speed. After electrical stimulation of the muscle using an electric stimulator (Grass SD9 B Square Pulse Stimulator), the muscle contracts and pulls on the upper wire that pulls the lever down and therefore the stylus will move upwards, and its trajectory will be traced on the rotating paper. When the muscle is relaxed, the stylus returns to its initial position and the plot returns to the starting level. The muscle movement is thus recuperated on the cylinder paper (see Figure 5). This impractical system has several disadvantages. Indeed, students, accustomed to using computer and interactive tools, find it difficult to understand the principle of the assembly maneuver and ask to be assisted to make the assembly of their workstation. In addition, several parameters such as the weight of the muscle, the length of the lever and stylus, the friction between the stylus and the recording paper, make the reel movement sometimes exaggerated and other times reduced which makes it difficult to calculate the amplification factor. Also, the manipulation of the ink contaminates the fingers of the students and consequently the muscle, which can be toxic to the muscle and therefore affect the results obtained.

Fig. 5. Picture of the used system

To overcome all these obstacles, the CAE-based system was tested and compared to the cylinder system. Indeed, during the last two academic years, 4 CAE stations were used in parallel with 4-cylinder stations. Each pair of students randomly uses one of two system types. The CAE assembly was quickly adopted by the students, more comfortable with the use of computer tools, who quickly understand and adopt the CAE sequence (see Figure 6). The sensor being sensitive to minim movements of few millimeters, it allows to reproduce the contraction movement with respect for the real amplitude of the muscular contraction.

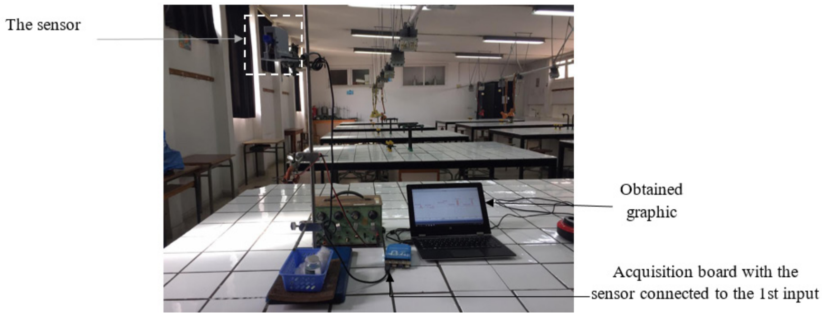


Fig. 6. Picture of the acquisition system based on the developed sensor

In addition, the graphic obtained is not a definitive, the student can amplify or reduce it to make the necessary measurements (see Figure 7 and 8). In the end, the developed system makes it possible to retrieve the results quickly and thus save the time that students often use to complete other tasks of analysis and interpretation of their results and preparation of reports. For subsequent sessions, students who have worked with the CAE system often ask at the beginning of the session to be placed again on a CAE station.

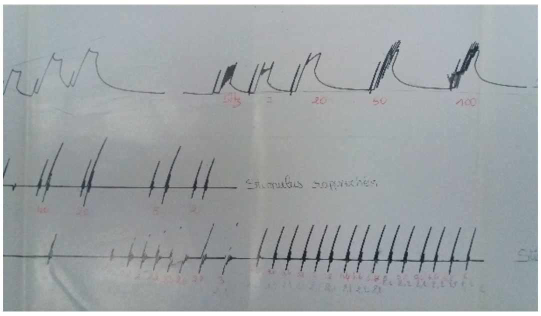


Fig. 7. Obtained results using the traditionnal system. Comments are added manuelly by students on the graph

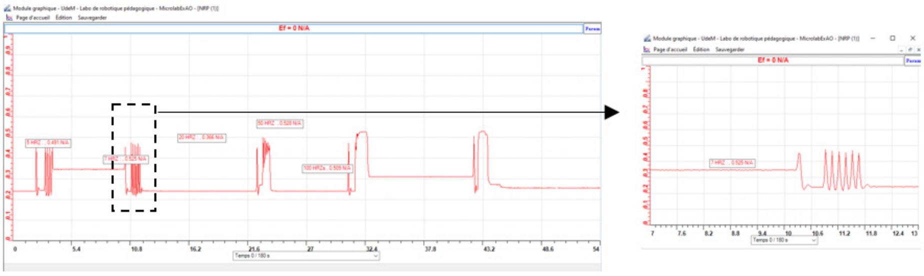


Fig. 8. Obtained results using the developed sensor. On the right the signal after zoom

4 Discussion

To evaluate the attitude of the students regarding the realization of the practical work with the realized sensor, we addressed an electronic questionnaire at the end of the sessions. 91 students aged between 18 and 26 years were interviewed, 74.7% of which are female and 83.5% have attended at least 4 sessions of animal physiology laboratory work.

The result of the survey shows that 79.1% of the population questioned (see Figure 9), prefer the use of the new sensor.

The reasons why these students prefer using the new system are mainly:

- easy understanding of the manipulation and the objectives to be achieved
- time saving, which allows more experimental activities during the lab session
- development of observations and scientific thinking skills
- possibility to adjust the precision of the results and to improve the presentation to facilitate the exploitation of the results
- ease of use of the developed system compared to the existing one

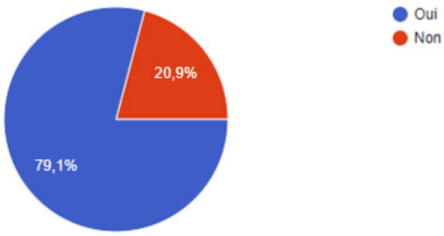


Fig. 9. Percentage of students according to their preferences, in blue the percentage of students who prefer to use the new system, in red those who prefer to work with the cylinder system

The students who prefer to use the cylinder system mainly mention the following reasons:

- the "MicroLab CAD/CAM" software is complicated and difficult to use
- the acquisition and processing of data is complicated

These reasons show indeed that these students prefer the old system because they have difficulties to handle the computer tools. Moreover, this percentage is in perfect agreement with that of the students who declared not having a personal computer (27.5%). Also, in the comment section, these students justified their preference for the cylinder system with comments such as "I prefer the cylinder, because don’t have a computer", "I don't master computer tools well" and "Because I have always worked with the cylinder" (see Figure 10).

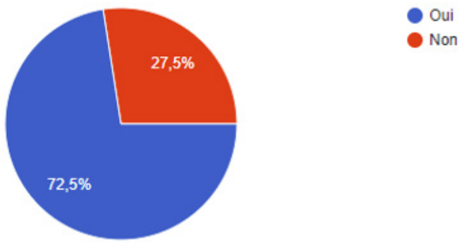


Fig. 10. Percentage of students, in blue those who have a personal computer, in red those who do not have a personal computer

5 Conclusion

Experimentation, an essential activity for developing students' critical thinking and manipulative skills, faces several problems. On a technical level, the system used for practical work in biology in higher education is expensive and presents several technical problems.

In this paper, we have presented a sensor of small biological movements realized with 3D printing and used in a CAD/CAM environment. According to the students, the didactic benefits of this new environment (i) facilitates their understanding of the PW, since they are more focused on the objectives of the PW and not on the adjustment of the system dedicated to the acquisition, (ii) which saves them time, (iii) facilitates the exploitation of the data, since the new system offers the possibility to amplify the sensor's output signal, to zoom in and to add comments on the graph in real time.

The 3D design and electronic schematics of the new system are open source, so the technical staff can repair and reproduce it at minimal cost.

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