Student demonstrator for teaching Brain-Computer Interfaces

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Abstract. One of the most exciting topics to teach to the students that follow the Biomechatronics lectures is Brain-Computer Interface (BCI). Its novelty as well as the sheer fact that one might control a computer via its brain waves is usually enough to guarantee implication. Unfortunately, there are no readily available student demonstrators on the market, which prompts the usage of research systems, and these are not easily configurable for laboratory demonstrations. This paper proposes two student demonstrators, describing the design process from conception, modelling, manufacturing and testing. The proposed demonstrators make use of the well-known motor-imagery BCI paradigm, one illustrating the basic principles, the other demonstrating a use-case as a rehabilitation upper-limb exerciser. The paper also reviews the current state of the art in the area of BCI systems for teaching.

1. Introduction
It is a well-known fact that teaching hard, dry subjects to the students might easily induce acute boredom, regardless how exciting the thematic might be; one of such subject is brain-computer interfaces (BCI), which is mainly based on high-level mathematics; as such, despite the fact that the subject arouse interest when is first announced, the extensive theoretical explanation required quickly snuff out any active attention. This is especially true for engineering students, many of whom are highly practice-oriented individuals.

There are many didactic methods dedicated to maintain and capitalise on students’ concentration; this paper deals with the design of a demonstrator which can be used as a tool of focusing the attention; as such, it is intended to give something to look forward to (which is the ability to control said demonstrator with a BCI) during the strenuous theoretical explanations. It is hypothesised that by setting this goal, one’s mind is better prepared to cope with the necessary intellectual effort for assimilating the necessary background.

Another role of the demonstrator is to facilitate the development of skills related to the setup and conducting an experimental activity, as well as data acquisition and interpretation competence. These aptitudes are nearly impossible to expand without the aid of a demonstrator. One last note before proceeding to the state-of-the-art research, the term “demonstrator” in this paper is used with reference to the equipment, not to the person who demonstrates the usage of said equipment.

2. State of the art
The scientific literature provides few examples of BCI demonstrators designed with the intent of providing support to the learning process, which is not a surprisingly odd development, as BCI was
until recently a field approached only from the research standpoint. As the technology reaches maturity, more and more applications outside of the research area are developed, and as such teaching materials become a necessity. Current interest in the field follows three main approaches: developing a framework into which to integrate research-grade BCI equipment for teaching purposes, developing demonstrators, and integrating BCIs into arts; for how various BCI applications fits the current framework, refer to figure 1. Relevant articles for the current paper were selected and discussed below.

**Figure 1.** Main application of today BCI systems

Maggi et al. [1] proposes a framework for development of in-house BCIs that take advantage of low-cost EEG acquisition units and several software solutions already present in an academic environment (e.g. Matlab). The viability of the tool chain was tested by implementing a steady-state visual evoked potentials (SSVEP) BCI, and the authors asserts that the main advantage of the framework is the fact that it opens the field of experimental BCI to individuals that have little theoretical foundation, by enabling them to use tools they are already familiar with from other subjects that are thought as part of their curriculum. Rutkowski [2] identifies three pillars that support successful teaching of BCI in a student lab environment: good acquisition hardware, flexible software and excellent sensory stimulus design platform. The same source cites several successful student projects based on various BCI paradigms concluding that this approach develops a useful skillset by introducing the students to modern digital signal processing and machine learning techniques. Kotona et al. [3] proposes a project-based learning method for BCI teaching; the cited source goes over a very well-thought schedule that spans over 30 weeks combining 19 hours of theoretical learning with 72 hours of laboratory work toward project completion. This kind of project exposes students to many useful practical skills like high-level programming, problem formulation and problem mapping and deepens the knowledge in digital signal processing algorithms, object-oriented model, database manipulation, etc. The cited study claims that compared with the control group, the students that took part in this project-based learning activity scored significantly better at the exams, despite the fact that the initial assessment showed that both groups had similar knowledge level, a fact that highlights the fact that learning in such a manner develops effective interdisciplinary competences. An interesting framework is proposed by Marchesi et al. [4], in which BCI becomes integrant part of the learning process: the described system monitors and tags the student attention and meditation levels observed from brain wave recordings, and correlates it with the lecture content, which might give insight to which part is more difficult; used as such, a BCI becomes a valuable feedback tool for teachers, as they get a clearer image of where additional explanation are needed and where the clarification might be shortened. A feature of this systems is the fact that it extends an existing e-learning platform and also works well with commercial BCI systems, which makes it particularly suitable for deployment on ultra-portable personal computers (tablets, smartphones, etc.).

An obstacle in using BCI in a teaching environment is their status as expensive research equipment, as no one wants to cope with the inevitable wear and tear; a solution is presented by Jain et al. [5], who propose a low cost system specifically designed with teaching in mind. The performance in terms of native electrical hum rejection, background noise level and harmonics is claimed to match those of
established commercial systems, both in dry runs and in actual data recordings. Volosyak et al. [6] describes an asynchronous control BCI system for a spherical robot that uses the SSVEP paradigm; a particularity of this study is the interfacing of BCI to the Robot Operating System, which enables the usage with a very large variety of robotic platforms. The cited study claims that during the preliminary testing, BCI naïve participants were able to intuitively drive the robot, which makes the systems especially suitable as a demonstrator, as students are not hampered by lack of skill in modulating their own brain waves for BCI control – like riding a bicycle, with some BCI paradigms is an acquired through repetition aptitude. Zhang et al. [7] propose a BCI system that decodes VEP brain waves into the object the user is thinking of and sends appropriate instruction to a 3D printer. The novelty of this avenue makes it especially suitable for laboratory demonstration and has the potential to incentivize the students to dedicate time to understand the underlying principles. The system has sufficient room for improvement, which could be used in a problem-solving learning paradigm.

BCI as a teaching framework is not limited only to engineering and computer science students: Yuksel et al. [8] introduce a BCI-system that tracks the cognitive workload of piano students and adjust the difficulty accordingly; it uses near-infrared spectroscopy, which is a method that employs different principles than the ordinary BCIs. The authors from the cited study asserts that compared to the control group, the participants learned musical pieces with increased accuracy; as a side note, they also observed that there was individual variation in the time needed for mastering certain levels of difficulty, which advocates for automated flexible tutoring systems. A general discussion for art in BCI is described by Andujar et al. [9] which states that artistic BCI in education is advantageous as it can give real-time feedback for a given task regarding the student’s level of attention, implication and understanding.

3. Design and testing of the user demonstrator
In the following paragraphs we will present two student BCI-demonstrators built in our laboratory; the first system (refer to figure 2.a) consists of a carriage $C$ actuated with a stepper motor $M$ through a transmission that consist of a single stage gear reducer ($z_1$ and $z_2$) and a cable $T$ wrapped around an active pulley $P_A$ and idle pulley $P_I$. The gear ratio is $i_{1,2} = 3.18$, which translates to a number of teeth $z_1 = 11$ and $z_2 = 35$; the chosen modulus for the gears is 1.75 mm; these were executed, like the rest of the system, out of polylactide (PLA) on a Prusa i3 Mk3 3D printer. The travel distance of the carriage is 130 mm with a maximum speed of 52 mm/s. The demonstrator is pictured in figure 2.b.

![Figure 2. Motor Imagery BCI demonstrator](image_url)
The motor is driven through a h-bridge by an Arduino UNO board; on its microcontroller, the program positions the carriage in the middle and listens on the USB communication for the appropriate commands: left or right movement. In order to generate these commands, a motor-imagery (MI) BCI paradigm is used, where the subject visualises left- or right-hand movement. An array of 8 g.Sahara dry electrodes are placed at the following positions, which corresponds to the international 10-10 EEG electrodes placement (figure 2.c): C3, C5, C6, Cz, C4, Fz, CP1 and CP2. The EEG signal is acquired using g.Mobilab+ biosignal amplifier, which provides a sample rate of 256 Hz/channel and a data sample of 16 bit; the acquired signal is filtered through a 4th order band pass Butterworth filter, with a low cut frequency of 1 Hz and a high cut frequency of 40 Hz (figure 2.d shows the raw and filtered signal; the large swing in the middle of the signal is jaw clenching myoelectric artefact).

On the software side the signal is referenced to the Fz and then spatially filtered with a surface Laplacian and then fed again through a 4th order band pass Butterworth filter, with a low cut-off frequency of 8 Hz and a high cut-off frequency of 24 Hz. After time based epoching, a classifier is trained using the well-known Linear Discriminant Analysis (LDA) algorithm; with the obtained classifier (which is unique for every subject), real-time control of the demonstrator is employed, in which the student moves the carriage left or right, according to his/her imagined hand movement.

The second demonstrator is a 2 degree of freedom shoulder-elbow exoskeleton, which was designed as a rehabilitation device and is described in these sources [10-11]. Its purpose as student demonstrator is to illustrate an application of the MI BCI in the field of rehabilitation engineering. The exoskeleton is attachable to a chair in point A (refer to figure 3) and consist of a link L1 where the arm of the subject is secured, and a second link L2 where the forearm is fastened. Joint B (shoulder) allows a range of −20°…+95° in respect to the frontal plane, and joint C (elbow) allows −90°…+60° in respect to the transverse plane. This range of movement is enforced by limit switches (for each joint, both for lower and upper bound) that are connected to a battery of antiparallel diodes and relays R in a normal close connection: therefore, if the driver D fails to stop the movement in time, the corresponding limit switches opens, and the relay cut the power to that motor in that direction, but the diodes allows the motor to operate in reverse, therefore a fault is automatically taken care of.

The BCI used to control this demonstrator is identical to the previous one, with the caveat that here only the imagined right-hand movement actuates the exoskeleton, as this was designed for the right-hand rehabilitation.

![Figure 3. Shoulder-elbow exoskeleton used as students’ demonstrator](image)
4. Conclusion
The presented demonstrators are handy for the usage in the laboratory activity with the students, as it focuses the attention on as of today unusually human-computer interaction; this allows to secure their attention to the activity and eases the discomfort of assimilating dry mathematical concepts necessary to understand the working principles and to program a BCI. The first demonstrator efficiently exhibits the basics of MI BCI in an easy to comprehend way. The second demonstrator highlights a use case of a MI BCI and opens discussions in which the students are encouraged to think of new ways in which a BCI system might be implemented.

Further work is needed in order to also demonstrate other BCI paradigms, as the sole focus on MI BCI does not fully depicts the full potential of BCI systems, due to the limitative nature of MI: low information transfer rate, few number of signal classes, etc. As the scientific literature review showed, other paradigms are also up to the task as student demonstrators. An additional avenue for investigation is the design of a low-cost acquisition system as a semester project.

5. References

[1] Maggi L, Parini S, Perego P and Andreoni G 2008 BCI++: an object-oriented BCI Prototyping Framework Proceedings of the 4th International Brain-Computer Interface Workshop and Training Course, Graz, Austria

[2] Rutkowski T M 2015 Student teaching and research laboratory focusing on brain-computer interface paradigms—A creative environment for computer science students 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC) DOI: 10.1109/EMBC.2015.7319188

[3] Katona J and Kovari A 2016 A Brain-Computer Interface Project Applied in Computer Engineering IEEE Transactions on Education 59(4) DOI: 10.1109/TE.2016.2558163

[4] Marchesi M, Ricco B 2013 BRAVO: A BRAin Virtual Operator For Education Exploiting Brain-Computer Interfaces Extended Abstracts on Human Factors in Computing Systems pp.3091-3094, DOI: 10.1145/2468356.2479618

[5] Jain A, Kim I, Gluckman B J 2011 Low Cost Electroencephalographic Acquisition Amplifier to serve as Teaching and Research Tool 33rd Annual International Conference of The IEEE EMBS, DOI: 10.1109/IEMBS.2011.6090535

[6] Volosyak I, Schmidt M 2019 Asynchronous Control of a Spherical Robot by Means of SSVEP-based Brain-Computer Interface The 7th IEEE International Conference on E-Health and Bioengineering DOI: 10.1109/EHB47216.2019.8969955

[7] Zhang X, Yao L, Huang C, Kanhere S S and Zhang D 2019 Brain2Object: Printing Your Mind from Brain Signals with Spatial Correlation Embedding The 26th International Conference On Neural Information Processing, submitted 2018.10.04 on arXiv:1810.02223

[8] Yüksel B F, Oleson K B, Harrison L, Peck E M, Afergan D, Chang R and Jacob R J K 2016 Learn Piano with BACH: An Adaptive Learning Interface that Adjusts Task Difficulty based on Brain State Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems pp.5372-5384 DOI: 10.1145/2858036.2858388

[9] Andujar M, Crawford C S, Nijholt A, Jackson F and Gilbert J E 2015 Artistic brain-computer interfaces: the expression and stimulation of the user’s affective state Brain-Computer Interfaces, 2:2-3, pp.60-69, DOI: 10.1080/2326263X.2015.1104613

[10] Ianosi-Andreeva-Dimitrova A, Novenu S, Tatar O M and Mandru D S 2016 Shoulder-Elbow Exoskeleton as Rehabilitation Exerciser 7th International Conference on Advanced Concepts in Mechanical Engineering, Iasi, Romania, DOI: 10.1088/1757-899X/147/1/012048

[11] Ianosi-Andreeva-Dimitrova A, Mandru D S, Tatar O M and Novenu S 2016 Motor Imagery Brain-Computer Interface for the Control of a Shoulder-Elbow Rehabilitation Equipment International Conference on Advancements of Medicine and Health Care Through Technology, Cluj-Napoca, Romania, DOI: 10.1007/978-3-319-52875-5_55