

MuLES: An Open Source EEG Acquisition and Streaming Server for Quick and Simple Prototyping and Recording

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ABSTRACT

The past few years have seen the availability of consumer electroencephalography (EEG) devices increase significantly. These devices, usually with a compact form factor and affordable price, now allow researchers and enthusiasts to use EEG in various new contexts and environments. However, the many consumer headsets often require extensive programming experience to interface with their respective drivers; moreover, standardization of the access and recording of EEG data across the devices still remains to be done. Consequently, a tool is needed to facilitate the recording and streaming of EEG data from consumer headsets that can easily be interfaced with different programming languages and software, and that allows interchangeability between devices. This paper describes the open source MuSAE Lab EEG Server (MuLES), an EEG acquisition and streaming server that aims at creating a standard interface for portable EEG headsets, in order to accelerate the development of brain-computer interfaces (BCIs) and of general EEG use in novel contexts. In addition to the EEG server interface which currently supports five different consumer devices and session playback, clients are developed for use on different platforms and in various programming languages, making prototyping and recording a quick and simple task. To validate the functionality and usability of the EEG server, a use case highlighting its main features is presented. The developed tool simplifies the acquisition and recording of EEG data from portable consumer devices by providing a single efficient interface, with applications in areas such as basic and behavioural research, prototyping, neurogaming, live performance and arts.

Author Keywords

Electroencephalography (EEG); Brain-computer interface (BCI); Neurogaming; Neurofeedback; Portable EEG.

ACM Classification Keywords

H.5.2 Information interfaces and presentation: User Interfaces – Input devices and strategies

INTRODUCTION

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Electroencephalography (EEG) is a non-invasive technique that measures the electrical activity in the cerebral cortex evoked by neurons' synchronized firing. By recording voltage levels between various points on one's scalp, this technique gives a global snapshot of the underlying brain activity [18]. Over the past decades, EEG has thus been used extensively for the study of neocortical processes, the diagnosis of diseases and the development of brain-computer interfaces. While traditional EEG devices were constrained to laboratory and medical settings due to their high cost, form factor and operation complexity, a wave of portable and affordable headsets came to the consumer market over the last few years [3, 13, 16]. The portability and availability of these consumer grade devices allow EEG to be applied in new unexplored ways, both in established application fields such as psychology, neuroscience and brain-computer interfacing, and in novel domains such as neurogaming, live performance and creative art.

Although they offer many advantages, these devices, coming from various vendors, do not offer a common standard interface. Indeed, each headset typically has its own application programming interface (API), software development kit (SDK) or communication protocol. Users with little or no programming experience, who are more likely to be interested by these new devices, may therefore be overwhelmed by the required work to get a headset functioning, thus hindering its usability in novel applications. Furthermore, interchangeability between EEG headsets, which is an interesting aspect when prototyping or expanding the use of an application across platforms, is very poor since the implementation must be modified for each different headset type. Software tools have been developed over the last few years to provide an interface for different EEG devices - mainly traditional research-oriented devices - generally for BCI programming [1], such as BCI2000 [22], OpenVIBE [21] and BCILAB [9]. However, these toolboxes are research-oriented and usually require good programming skills, and knowledge of EEG processing. The effort necessary to use them might still be prohibitive for many potential users, and overkill in applications where advanced processing features are not necessary.

In order to better meet the needs of this potential user base, the MuSAE Lab EEG Server (MuLES) was developed. This open source software tool provides a minimalist graphical user interface (GUI) to allow quick and simple interfacing with different portable EEG consumer devices. It implements a common interface for acquisition and recording of EEG

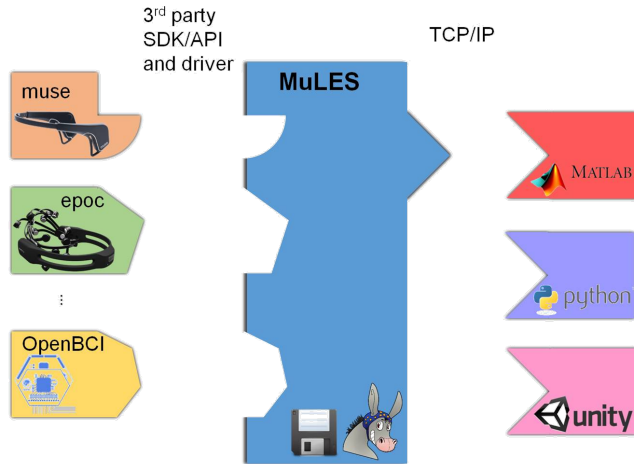


Figure 1. Architecture of MuLES: EEG devices are connected through their respective drivers, and communication to external client applications is done following the TCP/IP protocol.

data, as well as EEG data streaming over a TCP/IP connection. Example scripts for client applications are provided in different programming languages and development environments. The functionality and usability of MuLES was tested and validated during a 36-hour hackathon where its main features were used for prototyping a BCI-based game.

This paper is organized as follows: first, a technical description of MuLES is provided; second, a successful use case and potential applications are presented; finally, future work is highlighted.

TECHNICAL DESCRIPTION

MuLES is designed as the server part of a client-server architecture. As shown in Figure 1, the server handles the communication between the various EEG devices and makes their data accessible for client applications and/or logging. The source code and executables are provided under the MIT licence and freely available online [7].

Hardware layer

MuLES currently allows the use of one of five consumer EEG devices: InteraXon Muse [13], Emotiv Epoc [3], Neurosky Mindset [16], Neuroelectrics Enobio [5] and OpenBCI [19]. Clinical- and research-grade devices, not being the current focus of MuLES, are not yet supported. Nonetheless, pre-recorded data in CSV or EDF formats, recorded from either portable or research-grade devices, can be streamed in the present version of MuLES (v.1.0).

Data acquisition layer and user interface

Acquisition from the supported hardware is done through third party SDKs, APIs, drivers or direct implementation of the devices' communication protocol, as shown in Table 1. Additional hardware and drivers can be interfaced using native LabVIEW code, as done with the already provided open source implementations. Streaming of pre-recorded data is handled directly in the software.

Table 1. Devices supported by MuLES, including the name of the respective third party software used for communicating with the devices.

EEG Headset	API / SDK or driver	Price (USD)	Number of electrodes
Interaxon Muse	Muse SDK [14] Communication protocol implemented in MuLES	200	4, 6 ^a
Emotiv Epoc	Emotiv SDK ^b [4] and LabVIEW Emotiv Toolkit V2 [10]	400	14
OpenBCI V3	OpenBCI Dongle drivers [6] and LabVIEW OpenBCI Toolkit [11]	450	8, 16
Neuroelectrics Enobio	NIC software [8] Communication protocol implemented in MuLES	— ^c	8, 20, 32
Neurosky Mindset	Neurosky driver [12] and NeuroSky LabVIEW Driver [17]	100 ^d	1

^a Requires Muse Research Firmware

^b Research, Education or Enterprise Plus SDK is needed to get raw EEG

^c Under request

^d Estimated price, MindSet is not longer sold by NeuroSky

Quick access to the features of MuLES is allowed through its minimalist graphical user interface, shown in Figure 2. The GUI consists of four different sections: (a) input device selection, (b) recording and streaming controls, (c) start/stop acquisition and (d) current server state information.

Default parameters can be changed to adjust MuLES's recording and streaming behaviour (e.g., TCP port, data format and device settings) using an intelligible configuration text file. Moreover, MuLES can be called and run from the command line, making it easy to automate recording and streaming from external applications. Time markers can be sent at this layer during acquisition using the keyboard.

Data recording layer

EEG data and markers can be directly recorded in a custom CSV and/or standard EDF format, making it straightforward to import the data for analysis in different software packages (such as EEGLAB [2]) and programming languages.

Data streaming layer

Streaming to client applications is done using an implementation of the TCP/IP protocol, allowing data transmission on a single computer, over a local network or over the Internet. Client scripts can be written in any programming language supporting basic socket programming, such as MATLAB and Python. Additionally, clients can send markers back to the acquisition layer for recording in a file.

CHARACTERISTICS

Because it is developed in the LabVIEW ecosystem, MuLES can be easily adapted to run in other operating systems such as Linux and OS X. The toolbox is already compatible with 32- and 64-bit versions of the Windows OS. The LabVIEW runtime engine is required for running the application. Compiling the executable from source, which might be useful in some cases, requires a paying LabVIEW Application Builder licence. EEG device manufacturers' APIs and SDKs are also required for running the toolbox, but they are usually free.

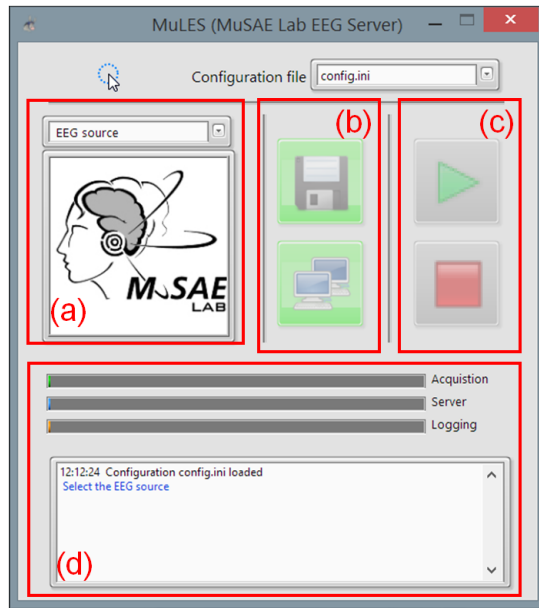


Figure 2. The graphical user interface (GUI) of MuLES and its sections: (a) input device selection, (b) recording and streaming controls, (c) start/stop acquisition and (d) current server state information

Although MuLES is based on LabVIEW, the reliance on the TCP/IP protocol means client scripts can be programmed in any programming language, and thus do not have to be in the same language as the server. This allows for great flexibility in designing new EEG processing applications and interfacing with already existing ones. For example, client applications could be implemented in a straightforward manner on mobile devices such as tablets and smartphones. In fact, this is the focus of ongoing work.

Above all, MuLES stands out amongst other similar alternatives thanks to its simple and easy to use GUI, currently available in English, Spanish and French. The minimalist interface makes recording and streaming EEG data to a client application a matter of a few clicks. MuLES is also controllable from the command line, making it easy to automate recordings and streaming sessions. Configuring a device is simple and can be done by modifying a comprehensive settings file. Furthermore, different profiles can be saved and loaded for each device, allowing their use in different scenarios without lengthening the setup time.

Sending and receiving triggers, a crucial task when collecting EEG data, is also supported and can be done by the user via a keyboard, or directly from a client application. However, it is to be noted that a lag of a few milliseconds makes the use of MuLES's triggers for event-related potential research unreliable. This is not problematic, however, for burgeoning applications that do not rely on precise time-locked events.

By running multiple instances of MuLES simultaneously, it is easy to connect and use multiple devices at the same time. This opens the way to new opportunities in studying social interactions and collaborative neurogaming with EEG devices.

Finally, since portable, consumer-oriented headsets are the primary focus of MuLES, support for standard, clinical-grade EEG devices is currently not available. These devices will however be considered in future releases of the toolbox. Similarly, recording and streaming from files is currently limited to a custom CSV format and the standard EDF format; other formats will be added in future iterations.

USE CASE AND APPLICATIONS

A neurogaming experience developed in under 36 hours

A preliminary version of MuLES was used during WearHacks 2014, a hackathon targeted at wearable devices that took place in the Fall 2014 in Montreal, Canada [23]. Teams of a few participants had less than 36 hours to design and develop an innovative product based on physiological and contextual data provided by wearables. In this context, a neurogaming project entitled *neuralDrift* was developed to show how EEG can be used in an entertaining way [15]. In the game, two players wear consumer EEG headsets that send neurophysiological data to a remote computer. This data is analysed in real-time to infer user intent, for example by mapping a meditative state (characterized by higher alpha power in the temporal and occipital regions of the brain) to a slowing down command, and a concentrated state (characterized by higher beta power in the frontal region of the brain) to an acceleration command. The commands are then sent to a robot that the two players must collaboratively control.

Due to the hard time constraints of the hackathon, MuLES was used to expedite the development process. First, exploratory data of users performing different mental tasks that could potentially elicit recognizable brain patterns was collected. The headset available at that time could be readily used to record EEG data with the quick data collection interface of MuLES. The data was then imported in an offline analysis tool to decide on the optimal control strategy to adopt. Second, during the design phase, MuLES was used to provide a single EEG data streaming interface compatible with any of the three different headsets available. The interfacing with the APIs and SDKs was handled by the EEG server, thus, no time was wasted on vendor-specific implementation details. Moreover, multiple instances of MuLES were used on the same computer to allow simultaneous recording and streaming from two players. Third, once the game prototype was functional, the use of MuLES in the backend allowed complete interchangeability of portable EEG headsets with minimal modifications to the implementation (such as the number of EEG channels to process).

While achieving similar results might have been possible using other EEG toolboxes, the minimalist approach of MuLES allowed a quick and simple setup and supported all the available EEG headsets. These features made the prototyping steps particularly efficient in the context of a hackathon and allowed the team to produce a functional prototype. Moreover, new features have since been added to MuLES following recommendations from the team, such as the capacity to connect to multiple devices of the same type using multiple MuLES instances, logging in different file formats, and example client scripts in other programming languages.

Potential applications

Many fields that already benefit from EEG research as well as new application fields could take advantage of a tool allowing efficient interfacing with portable consumer EEG devices. In established research fields, such as psychology, cognitive science and brain-computer interfacing, amongst others, users can now rapidly make use of affordable EEG headsets outside of standard laboratory settings. Newcomers to these fields can also start to collect and use EEG data much faster.

New application fields can also benefit from the possibilities enabled by MuLES. For example, art and live performances can readily use EEG data as part of exhibitions and shows, allowing new immersive experiences. The development of neurogaming applications, such as the *neuralDrift* discussed above, can be greatly simplified by such a tool as well.

CONCLUSION AND FUTURE WORK

The MuSAE Lab EEG Server (MuLES) is an open source EEG acquisition and streaming server with a simple unified interface for portable EEG headsets such as the Emotiv EEG [3], the InteraXon Muse [13] and the OpenBCI [19], allowing prototyping and development of EEG applications in traditional and novel contexts such as brain-computer interfacing.

Developed in LabVIEW and making use of the TCP/IP protocol, MuLES can be used on and across multiple platforms and programming languages to record and stream multi-channel EEG data. Its functionalities were tested and validated during a hackathon, which gave rise to the *neuralDrift*, a neurocomputing game based on portable EEG headsets.

Future versions of the toolbox will include many improvements and new features: compatibility with other operative systems; support for clinical-grade EEG devices; support for non-EEG devices (such as electrocardiography, galvanic skin response and temperature sensors); integrated computation of basic EEG features such as frequency transforms; support of other file formats for recording and streaming; and example clients in other programming languages and software frameworks such as Unity. Specific communication protocols for each device can also be implemented to provide more advanced functionalities (such as getting other available information: accelerometer data, contact quality information, etc.) and an optimized functioning (for example in embedded applications).

In the end, it is hoped that MuLES will make research and application development with EEG easier and more accessible.

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