

From model to methods: on the Evaluation and the Optimization of Brain-Computer Interface Systems

Lucia Rita Quitadamo¹, Maria Grazia Marciani^{1,2}, Luigi Bianchi^{1,2,3}

¹*University of Rome “Tor Vergata”, Neuroscience Dept., Rome, Italy*

²*Fondazione S. Lucia IRCCS, Rome, Italy*

³*Centro di Biomedicina Spaziale, “Tor Vergata” University, Via della Ricerca Scientifica snc, 00133 Rome, Italy*

Abstract-Brain Computer Interface (BCI) systems have gained great visibility in the last years for the possibility they give to severely disabled people to have a normal interaction with the external environment. However every group implements its own BCI system and this leads to a lack of a common language concerning methods, names of BCI components, file formats, tools etc..., with an obvious difficulty in sharing data and resources among labs. This is the reason which induced us to develop a set of methods and tools for the optimization and dissemination of resources dealing with BCI systems.

Keywords-BCI, Functional Model, Metrics, XML, UML.

1. INTRODUCTION

Brain Computer Interface (BCI) systems are a set of the more general Human Computer Interaction (HCI) systems which allow a direct channel of communication between people with severe muscular disabilities and the external environment, by translating their brain signals into commands toward output peripherals [1]. A lot of disciplines are involved in the BCI research field, including neurology, engineering, psychology, informatics, rehabilitation etc...; this requires a separation of the competences of the different groups, which could be interested in developing different aspects of BCI systems and so need to start from a common model and then have open file formats for data exchanging and analysis tool to process them.

2. THE PROBLEM

Among the major issues of the field there are the evaluation and optimization of the performances of BCI systems and the standardization of the resources dealing with them: a clear definition of both of them lacks to date, even if it is absolutely necessary for a worthwhile comparison of systems and for the selection of the most useful system to adapt to the needs of the end user.

3. THE POSITION OF THE DEPARTMENT OF NEUROSCIENCE OF THE “TOR VERGATA” UNIVERSITY

Our laboratory has implemented the Body Language Framework (BF++) [2], a set of C++ routines for the design, implementation, optimization and delivery of cross-platforms BCIs, which we hope everyone would download for their own purposes and for sharing resources (www.braininterface.com). We think that the use of open standards, spanning from file formats to metrics for the evaluation of systems and to functional models for the description of the most diffused BCI systems, could help in the dissemination of resources and in the communication among labs.

The framework implemented includes a functional model, a metric, a new file format, software tools and a UML model, which will be explained in the following sections.

Functional Model and Metric

The core of our framework is the functional model described in Mason et al. [3], in which BCI systems are constituted by two main blocks: the Transducer and the Control Interface (Fig. 1).

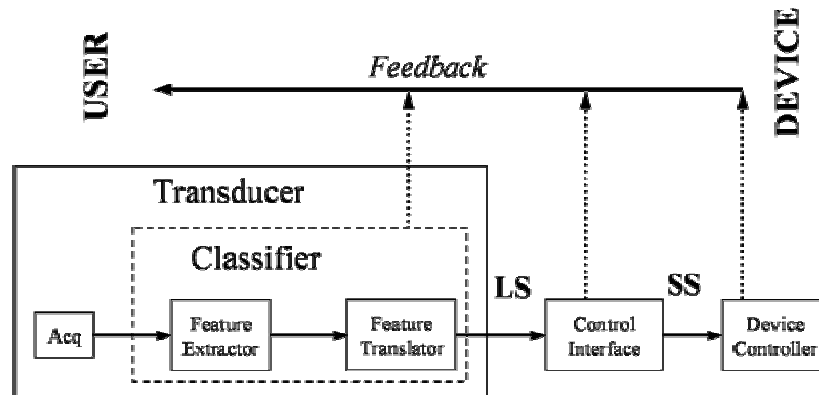


Figure 1: Functional model of a BCI system.

The Transducer deals with the acquisition of physiological signals (Acquisition Stage), with the extraction of features of interest from them (Features Extractor) and with the translation of these features (Features Translator) into a Logical Symbol (LS), which constitutes the output of the classifier and then the input towards the Control Interface.

The Control Interface, instead, translates a LS or sequences of LSs into a Semantic Symbol (SS) by means of encoding strategies: for example, with permutations on sequences of three logical symbols (α , β , γ), the entire English alphabet plus the space character can be encoded [4]. SSs are matched into commands toward the external device (e.g. to draw a letter on a PC screen).

It is important to stress the fact that in general each LS is correctly classified with a different probability (different performances of the Transducer) and that the Control Interface can implement different encoding and error correction strategies (different performances of the Control Interface), so that the choice of the best BCI system can originate only from the choice of the best combination Transducer-Control Interface; in other words, the best Transducer and the best Control Interface do not exist, but just the best combination of them.

Classical metrics such as Mutual Information [5], Bit Rate, Entropy, etc... fail in the purpose of evaluating the performances of BCI systems as a whole, as they do not take into account how transducers and control interfaces adapt each other or how the system behaves when errors occur. In this regard we have implemented a new metric [4] which evaluates the performances of BCI systems by means of:

- a) The description of the characteristics of the Transducer through the Extended Confusion Matrix (ECM), which identifies the classifier (including abstaining classifiers [6]).
- b) The characterization of the consequences of errors and abstentions by assigning a cost to them.

Finally the efficiency of a system is computed by considering both the contributes previously mentioned, that is, it is a consequence of the adaptation of the Transducer and the Control Interface to each other. This way of characterizing the efficiency of a system is valuable as the metric becomes very reliable (the cost of errors and their restoration are taken into account) and the Transducer and the Control Interface can be implemented separately and then tuned to find the most efficient system.

An XML-based File Format for storing and manipulating BCI data and neurophysiological signals

We used the XML technology in order to implement a powerful file format for the storage of BCI entities and of huge quantities of neurophysiological data and to allow the sharing of data among different laboratories. By following some simple strict syntactic rules everyone can define the structure of a XML document: XML tags are unspecific, easy to understand and can be extended without breaking the compatibility with preexistent data or tools. This technology is supported by a lot of platforms and operative systems so that data can be exchanged without errors and with no need of special software conversion tools. It also contemplates a lot of technologies which handle data stored in a file and which satisfy a huge amount of requirements.

In our framework all the entities involved in BCI systems such as encoders, ECMs, logical and semantic alphabets etc... have been stored with the XML format. Also a flexible file format for representing electrophysiological data has been defined. It is also based on the XML technology and called NPX (NeuroPhysiological data in Xml) [7]. It supports a virtually unlimited number of sensors and events. Data can be stored in various ways with respect to the accuracy (8, 16, 32, 64 bits), the internal representation (integer, floating point) and where the data are stored: because XML files are not as efficient as binary ones, if the amount of sampled data is huge (e.g. an EEG recording) they can be stored in an additional distinct binary file, otherwise (e.g. ERP, spectral data) they can be stored in the XML file itself. In both cases the XML file will contain a complete description of the sensors (dynamics, number of bits, gain, coordinates, etc...), events (type, occurrence, etc...), processing, etc....Source code to read and write a NPX file is available and written in ANSI C++ to allow an easy porting under virtually any platform.

Software tools: BF++Toys and NPXLab

A set of C++ routines have been implemented for the evaluation and optimization of BCI systems, the BF++Toys, which also implement methods for computing the metric previously described and are formed by some modules which simulate the characteristics of the Transducer, generate new encoders, assemble transducers and control interfaces and finally find out the best combination of them, thus allowing to build the most performing system.

NPXLab, instead, is a software tool for the processing and analysis of physiological data stored in the NPX format: it allows to perform spectral analysis, to extract ERP from EEG data, to perform statistical analysis and the Independent Component Analysis.

The Unified Modeling Language (UML) model

We have also implemented [8] a UML model for the description of different BCI systems and equipped it with a set of definitions of the most diffused and “confused” terms dealing with BCI (for example, is the trial the same entity for every research lab?). This model catches all the properties of the most diffused BCI protocols (P300, mu-rhythms, Slow Cortical Potentials, Steady State Visual Evoked Potentials, fMRI, etc...) and by means of some diagrams it describes both the static (class diagrams) and dynamic behaviors (sequence diagrams) of these systems. It can be used as the starting point for the implementation of new systems.

4. CONCLUSION

BCI systems are manifold and complex and require the collaboration of different disciplines. At the Neuroscience Department of the “Tor Vergata” University of Rome, we think that this collaboration is of primary importance for the optimization of these systems. In this regard we have implemented a

model of BCI systems, which fits to the BCI protocols most diffused to date and which is the starting point for the implementation of standard file formats for the sharing of data and of tools for the analysis, evaluation and tuning of systems [9]. All these resources can help in the optimization and the dissemination of BCI systems.

The tools and file formats we implemented can be downloaded for free at www.braininterface.com: some of the sources are available there, so that everyone can modify or extend them according to his needs, implementation, operative system etc..., as all the resources we place at everyone's disposal are highly compatible with a lot of platforms.

ACKNOWLEDGMENTS

This work was partially supported by the DCMC (Disorders of Motor and Cardio-respiratory Control) Project of the Italian Space Agency (ASI).

REFERENCES

- [1] J. R. Wolpaw, N. Birbaumer, D. J. McFarland, G. Pfurtscheller and T. M. Vaughan, "Brain-computer interfaces for communication and control," *Clin. Neurophysiol.*, 113(6), 767-791, 2002.
- [2] L. Bianchi, F. Babiloni, F. Cincotti, S. Salinari and M. G. Marciani, "Introducing BF++: A C++ Framework for Cognitive Bio-Feedback Systems Design", *Methods Inf. Med.*, 42(1), 104-110, 2003.
- [3] S. G. Mason, M. M. Moore Jackson and G. E. Birch, "A general framework for Characterizing Studies of Brain Interface Technology," *Ann. Biomed. Eng.*, 33(11), 1653-1670, 2005.
- [4] L. Bianchi, L. R. Quitadamo, G. Garreffa, G. C. Cardarilli and M. G. Marciani, "Performances Evaluation and Optimization of Brain-Computer Interface Systems in a copy spelling task", *IEEE Trans. Neural Syst. Rehabil. Eng.*, 15(2), 207-216, 2007.
- [5] A. Schlögl, C. Keinrath, R. Scherer and G. Pfurtscheller, "Information transfer of an EEG-based brain computer interface". In *Proceedings of the 1st International IEEE EMBS Conference on Neural Engineering*, Capri Island, Italy, Mar. 2003.
- [6] T. Pietraszek, "Optimizing abstaining classifiers using ROC analysis". In *Proceedings of the 22nd International Conference on Machine Learning*, Bonn, Germany, Jun. 2005.
- [7] L. Bianchi, L. R. Quitadamo, M. G. Marciani, B. Maraviglia, M. Abbafati and G. Garreffa, "How the NPX data format handles EEG data acquired simultaneously with fMRI", *Magn. Reson. Imag.*, 25(6), 1011-1014, 2007.
- [8] L. R. Quitadamo, M. G. Marciani and L. Bianchi, "Describing different Brain Computer Interface Systems through a unique model: a UML implementation", *submitted*.
- [9] L. R. Quitadamo, M. Abbafati, G. Saggio, M. G. Marciani and L. Bianchi, "Brain-Computer Interface research at the Neuroscience Department of the "Tor Vergata" University of Rome, Italy". In *Proceedings of the 29th Annual International Conference of the IEEE EMBC*, Lyon, France, Aug 2007.