FROM THE UNSEEN TO THE S[CR]EEN ESHOFUNI, AN APPROACH TOWARDS REAL-TIME REPRESENTATION OF BRAIN DATA

HORÁCIO TOMÉ-MARQUES

Faculty of Engineering
University of Porto and School of Music and Performing Arts, IPP
Portugal

horacio.marques@fe.up.pt

JOÃO MENEZES

ID+ Instituto de Investigação em Design, Media e Cultura
University of Porto
Portugal

joaommenezes@gmail.com

BRUCE PENNYCOOK

College of Fine Arts, University of Texas at Austin
United States of America

bpennycook@austin.utexas.edu

MIGUEL CARVALHAIS

ID+ / Faculty of Fine Arts, University of Porto
Portugal

mcarvalhais@fba.up.pt

Keywords: Brain Signal Representation, Data Visualization, MAX MSP/Jitter, Virtual Physics, Art

In this paper we propose an approach towards real-time representation of brain data using a virtual physics engine built in the Max MSP/Jitter graphical programming environment, and with the real-time raw Emotiv EEG BCI signal. Firstly we summarize about the brain as an electric phenomenon and as a perpetually active system dependent of an environment. Secondly we describe methods of representation of these phenomena in historical contexts such as science and art. We then establish a conceptual relationship between brain's phenomena and Newton's laws of motion and equilibrium. Finnaly we discuss potential gaps to be fulfilled and propose and describe *EshoFuni*.

1. INTRODUCTION

The human brain is a complex system that generates electric signals. It is "perpetually active, even in the absence of environmental and body-derived stimuli" (Buzsáki 2006, 10) but needs environmental inputs to create useful activity. The electric phenomena of the brain have been being recorded in the form of waves, i.e., sinusoids with frequency and amplitude, to which Hans Berger, the pioneer of brain potentials recording called "continuous curves with continuous oscillations"[1] (Hirnströme 2005). The first report of scalp recording based on a representational methodology – photographic – of the human brain's electric potential was made by Berger at the start of the twentieth century (Desney and Anton 2010) a process that he called *Elektrenkephalogramm*.

During that century, other methods of Electroencephalogram (EEG) representation were invented and implemented e.g., the Toposcope, devised by William Grey Walter, that allowed topographic visualization (Walter, 1951). Artistic approaches also have been being devised. In 1965 Alvin Lucier used EEG signals to acoustically or mechanically active musical instruments (Miranda and Brouse 2005), i.e., he proposed a representation of those potentials through sound. The development of computation occurred after the second world war catalyzed a continuous development of systems, both hardware and software, to acquire, treat, translate and represent both nature constituents (physical objects and events) and human abstractions phenomena (conceptual objects and events), to generate data that could allow us to understand these phenomenons or to create new ones, e.g., metaphors, virtualizations, of this same constituents.

Both sciences and arts have been using representational methodologies based upon different strategies, conventions and purposes, e.g, topographic visualization, i.e., the possibility to denote specific occurrences within specific regions of the brain's geography – event(s) and place(s) of a phenomenon – , uses (pseudo)color coding schemas to denote and characterize both constituents (Shankar and Ramakrishnan 1951; Teplan 2002).

The representation of the brain's electric phenomena needs a process – acquisition, transduction, processing, post-processing – that translates the analogic signals into digital data, via discretization, and from that into repre-

1 Free translation from the German original: " (…) eine fortlaufende Kurve mit ständigen Schwankungen (…)" (Hirnströme, 2005).

sentational forms (Teplan 2002). The representations can be substantiated via offline or online processes, i.e., can be devised *a posteriori* or in real-time.

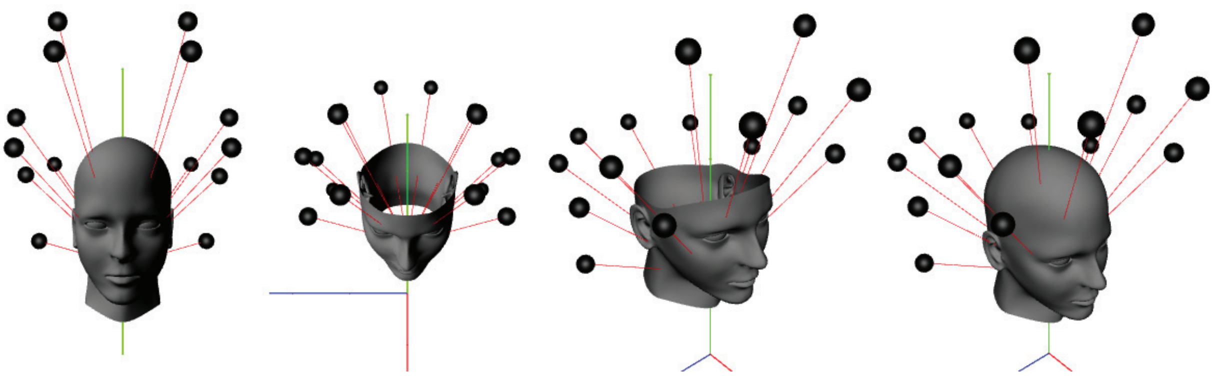
There are now many EEG representational approaches but many are restricted by autoregulation paradigms (e.g., within science) and although they may allow reconceptualization and evolution, they replicate the conventions and theoretical frameworks from which they depend upon, i.e., restrictive and closed positions. Within arts, approaches have been proposed during the last years, mostly related to performative arts such as music (Miranda and Wanderlay 2005). However EEG representation within the arts is still in its infancy. As such it is an emergent opportunity to research, propose and repurpose representational approaches. Our motivation is anchored on a double aspect, since we are dealing with two constituents of a correlated phenomena, i.e., methods of representation of the brain electric phenomena, as well as the phenomena itself. As such, besides the representational aspect, our approach is also framed on a conceptual parallelism inspired on Newton's laws of motion and equilibrium and a theory that proposes that the brain has a default state. Newton postulated that a body continues in its state of rest – or of uniform motion – , unless external forces compel it to change that state (Newton 1728). The same happens with our brain, it has a default mode. In this mode "it develops as a self-organized or spontaneous state without an external input", however, external perturbations are crucial to brain to perform useful computations (Buzsáki 2006).

This project is part of a broader research where we pursue the creation of innovative content. During this process we are often confronted with the lack of ways to "materialize" our ideas. As an answer, and besides creating content, we also have been developing strategies and devices focused on solving these problems where and when they may arise.

In order to fulfill the gaps identified above, we developed *EshoFuni*, a tool that develops a physical simulation to visualize EEG data in real time. With *EshoFuni*, we aim to offer a robust and reliable tool that promotes a non-linear real-time representation of EEG data. *EshoFuni* is intended as a flexible tool that adapts to new needs and paradigms in the representation of EEG data.

Taking this into account, we chose the graphical programming environment Max MSP / Jitter as the development platform. This choice lies in several factors: on one hand, the flexibility offered in the development and maintenance of the system; on the other, the fact of being a cross-platform environment that is well established in the field of digital media and performing arts, enhancing the likelihood of its acceptance and maintenance by the community, that may easily contribute to the improvement of existing functions, and the development of extensions to address emerging paradigms in the field.

Fig. 1 Different views of the representation provided by *EshoFuni*



2. PROJECT

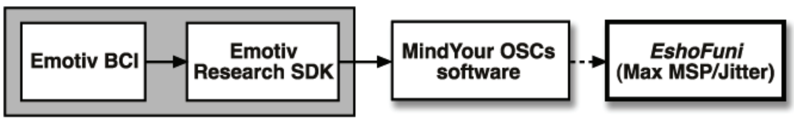
2.1. TECHNICAL SPECIFICATIONS

The system comprises the following hardware and software:

1) Brain Computer Interface by Emotiv (BCIEEEG);
2) Computer(s);
3) Emotiv Research SDK (ERSDK);
4) Mind Your OSC[2] (MYOSCs) ;
5) Max MSP/Jitter (MM/J).

2 Mind Your OSCs uses the Open Sound Control (OSC) protocol to bridge data between ERSDK and MM/J. This software has two versions: one that connects to the Emotiv Control Panel, which allows access to Emotiv proprietary algorithms that fulfill personalized Emotiv paradigms, and another that connects directly to the ERSDK which allows access to the raw data. At the time of the redaction of this document this latter version only exists in Windows platform.

Fig. 2 Scheme of the general architecture of the system implementation



2.2. SYSTEM OVERVIEW

As illustrated in Fig. 2, brain data gathered by the BCIEEEG is wirelessly sent to the ERSDK; MYOSCs is used to establish a wireless bridge between ERSDK and MM/J, using the OSC[3] protocol; the data coming from MYOSC is received in MM/J through a UDP[4] connection, and treated as described in 2.3.1.

BCIEEEG records brain electric signals with 14 channels based on the International 10-20 system[5] on the locations AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF4. Emotiv device sends via wireless and USB/Bluetooth interface to the host, i.e., e.g., the computer that hosts the ERSDK, a stream of encrypted data – encrypted by the device's proprietary system. The data is decrypted by the ERSDK. All data exported by the API is raw EEG values in microvolts (μV). EEG data is stored as floating point values directly converted from the unsigned 14-bit ADC output from the headset. DC level of the signal occurs at approximately 4200 μV (Emotiv, 2008).

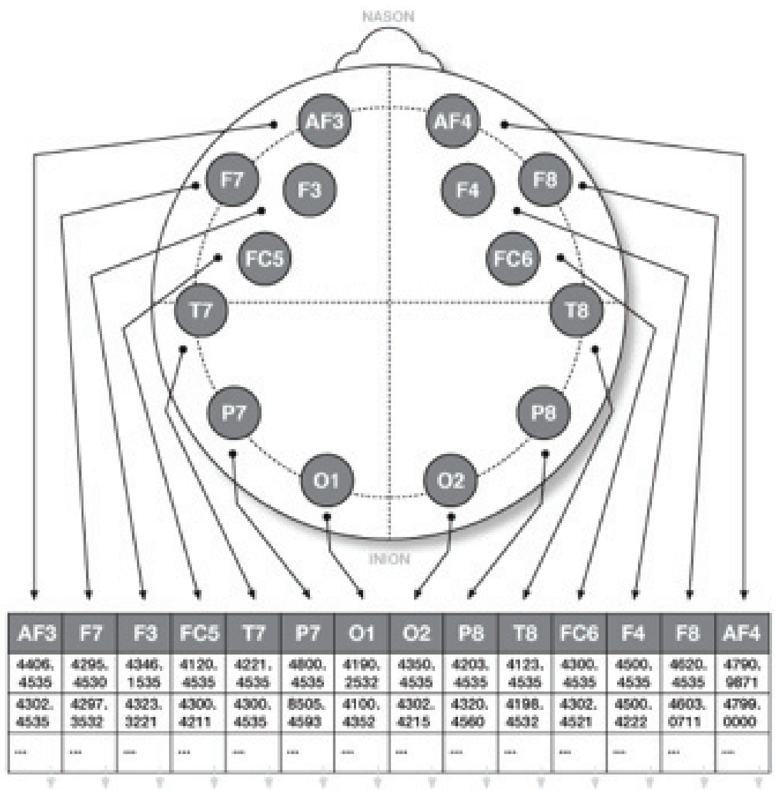


Fig. 3 Relationship between Emotiv channels and incoming data vectors (derived from EDK Channels Enumerator – Emotiv Research SDK)

A physics engine programmed in MM/J applies internal algorithms based on real-world physics, allowing us to simulate a given virtual scenario. It provides internal algorithms that allow us to setup virtual worlds with

3 Open Sound Control (OSC) is an open, transport-independent, message-based protocol developed for communication among computers, sound synthesizers, and other multimedia devices. An OSC packet can be naturally represented by a datagram by a network protocol such as UDP (opensoundcontrol.org).

4 The User Datagram Protocol (UDP) is one of the fundamental members of the Internet protocol suite, designed in 1980 by David P. Reed, formally defined in RFC 768. "This protocol provides a procedure for application programs to send messages to other programs with a minimum of protocol mechanism (http://tools.ietf.org/html/rfc768).

5 A standardized physical placement and designations of electrodes on the scalp, adopted in 1955 by the International Federation in Electroencephalography and Clinical Neurophysiology (Teplan 2002).

complex dynamics. Entities such as rigid bodies – which can have distinct shapes, masses and sizes – are subjected to force vectors (e.g. gravity) and can interact with each other (e.g. collide, constraints). The result of these interactions is based on the dynamics of the system.

2.3. ARCHITECTURE

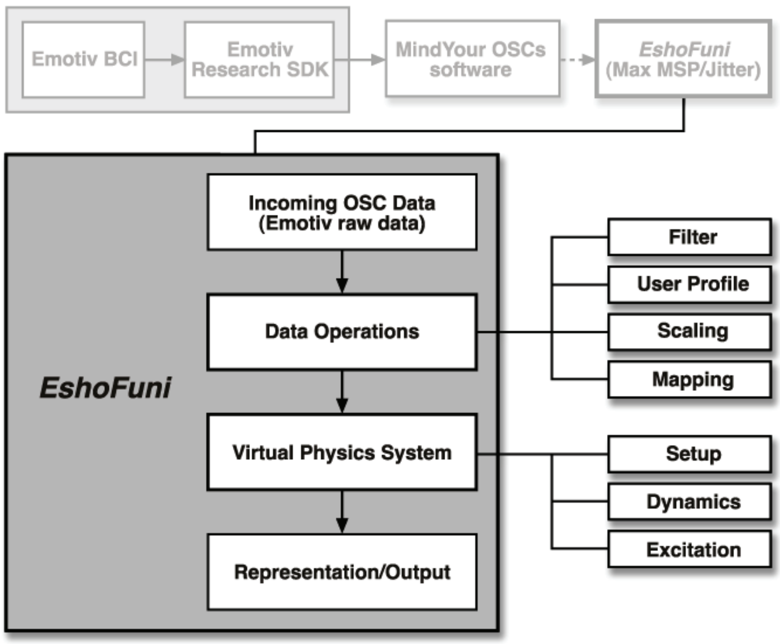


Fig. 4 *EshoFunni*'s architecture. OSC Raw data incomes as a stream of floating point values with an average level of 4200, (which represents the DC offset level of the signal that occurs at approximately 4200 µV). This data is firstly subjected to different data operations (2.3.1), and then sent into the virtual physics system (2.3.2) provided by the MM/J, as a means to create and simulate a conceptual metaphor of the 10-20 system representation.

2.3.1. DATA OPERATIONS

Filter: raw data is subjected to filtering operations, more precisely, a low-pass and a band-pass filter. These can be applied or not, with frequencies adjustable by the user. Additionally, the moving average for each data vector is calculated, for purposes of monitoring as well as to trace a user profile, described below.

Profile: Each individual has a default mode, i.e., a mode that works permanently within a self interdependent dynamics, where the constitutive parts of the individual are permanently exposed and interact within the environment where it inhabits, i.e. itself. Consequently each individual has an offset signal dependent of its default mode.

An excitation, i.e., a(ny) stimuli that does not belong to default mode is what provokes a chain of reactions that modulates the default mode, i.e., generates a signal scale dependent of the interaction of the individual with its environment. Taking this into account, the system collects data and proceeds with a statistical averaging to establish a default mode for each user. This default mode is then the starting point from which the system behaves, more precisely, the default mode values are inserted as the base for the scaling process, described in the next paragraph. Different profiles settings can be stored and accessed at any time. Thus, allowing the system to easily adapt to different subjects.

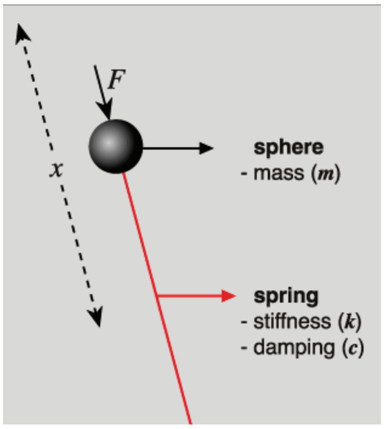
Scaling: Once the data is filtered and a profile of the subject is plotted, we proceed to the scaling process. Originally comprised between 4200 and 5000 (based on the original DC offset of the raw signal), the data is scaled to values between -5 and 5. These will be translated into vectors with a given magnitude and direction, which will act in the form of forces when applied to the physical system (see 2.3.2). The default scaling translates higher EEG values into high magnitude force vectors, and lower EEG values into low magnitude force vectors. By default, the transfer function used in the scaling process is an exponential function of base 2.5. However, cosine, linear, logarithmic, and gaussian functions can be applied, among others. Scaling has a significant impact on the relationship between the input data and the physical forces applied to the system (described in 2.2). For this reason, the possibility of the user to change the scope of scaling as well as its underlying transfer function, translate into important features in the search for a balanced representation of EEG data with different characteristics.

Mapping: At the end of these processes, with properly filtered and scaled data, we proceed to the mapping process. Here, data vectors are translated into forces that will be later introduced in the virtual physics system, described in 2.4. Additionally, there is also a relationship between the activity level of a given EEG channel, and the virtual sphere that represents it.[6]

2.3.2. PHYSICS SYSTEM

The physics system was developed by Hermann (1999) having into account the methodology for the development of an interactive sonification model. Despite its connection to the discipline of Auditory Display and Data Sonification, we did not find any objection for its application in this context. As such, we divided this visual representation system according to its (i) Setup, (ii) Dynamics, and (iii) Excitation.

Fig. 5 Mass-spring system



6 *EshoFuni* allows, at this moment, to map EEG activity to pseudo color code as well as to size.

i) Setup: The proposed visualisation model, is composed by one mass-spring system per data vector (EEG channel), each virtual spring being attached at 3D spheres whose positions are defined by the 10-20 system described in the section 2.2.

ii) Dynamics: As illustrated in Fig. 5 each sphere (with a mass m) is fixed with a virtual spring to its position in the three-dimensional (3D) space, thus, each sphere can perform an harmonic oscillation around its own position, as described by x. This harmonic oscillation is modeled by classical mechanics of mass-spring systems, which is determined by an external force (F), the mass of the sphere (m), the spring stiffness (k), and the damping coefficient – or dissipation rate – (c). At the moment, all spheres share a mass of 2 (m = 2 kg). The same happens with the springs, sharing a stiffness of 15 (k = 15kg s^{-2}), and damping coefficient of 5 (c = 5kg s^{-1}). It is important to note, that these values were set after some tests with different EEG data streamings. However, the user is able to change these values according to his purposes, thus adapting the physical simulation to different EEG data streamings and its features.

iii) Excitation: Initially in its rest state, the model is excited by being introduced a given force (F) in its dynamics. These forces act as vectors with a given magnitude and direction, which will then be applied in the equations of motion of each sphere. Therefore, the change of motion of each sphere, is proportional to the force impressed and is made in the direction of the straight line in which the force is impressed. Vector's magnitude and direction are directly related to the mapping and scaling sections (see 2.3.1), thus, changes in the scaling process (scale values and transfer function) will be reflected on the applied force, and therefore, on the harmonic oscillation performed by each sphere.

3. CONCLUSIONS AND FUTURE WORK

We presented *EshoFuni*, which according to our research is the first system making use of a physics simulation to visually represent real-time EEG data. Being one of the most important purposes of *EshoFuni* to solve personal problems and needs on creating artistic representations of brain electric phenomena (e.g. by means of sound or graphic form) we consider that the way it fulfills that requirement is rather consistent and satisfactory – maybe groundbreaking by itself.

We finally hope that it may contribute to successfully represent this kind of data, particularly in the domain of digital arts. Additionally, the flexibility provided by *EshoFuni* should promote a systematic and versatile approach for data representation within different artistic contexts.

As described in section 2.2, the actual data transmission is based on OSC protocol, provided by MYOSCs. This increases the risk of packet loss along the transmission, thereby representing the major limitation of *EshoFuni*. Having this into account, future work should be centered around the development of a MM/J external, that provides data acquisition to be done directly from the EMRSDK, instead of using third-party software (e.g. MYOSC) to bridge between EMRSDK and MM/J. In this way, we would be able to remove the actual intermediary protocol (i.e, in this case, OSC), thus increasing *EshoFuni*'s robustness and speed, as well as the decreased risk of packet loss. Finally, it is in our interest to implement methods of real-time analysis and artifact removing, thus enhancing rigorous data interpretation and system behaviour.

ACKNOWLEDGEMENTS

This project was partially funded by FEDER through the Operational Competitiveness Program – COMPETE – and by national funds through the Foundation for Science and Technology – FCT – in the scope of project PEst-C/EAT/UI4057/2011 (FCOMP-Ol-0124-FEDER-D22700).

REFERENCES

Buzsáki, György. *Rhythms of the Brain.* Oxford: Oxford University Press, 2006.

Cornelius Borck Hirnströme. *Eine Kulturgeschichte der Elektroenzephalographie.* Göttingen: Wallstein Verlag, 2005.

Hermann, T, and H Ritter. "Listen to Your Data: Model-Based Sonification for Data Analysis." *Int. Inst. for Advanced Studies in System Research and Cybernetics*: pp. 189–194., 1999.

Newton, Isaac. *Mathematical Principles of Natural Philosophy.* In Two Volumes. London: Benjamin Motte. Published 5 July, 1728.

R. Miranda, Eduardo, Brouse, Andrew. *Toward Direct Brain-Computer Musical Interfaces. in* NIME '05 Proceedings of the 2005 conference on New interfaces for musical expression. Pages 216 - 219. Singapore: National University of Singapore, 2005.

R. Miranda, Eduardo and M. Wanderley, Marcelo. *New Digital Musical Instruments: Control And Interaction Beyond The Keyboard.* Middleton: A-R Editions, Inc., 2006.

R. Murali Shankar and A. G. Ramakrishnan. *Topographic Mapping Of The Brain Electrical Activity.* Proc. Nat. Conf. Biomed. Eng., Manipal, April 9-11, 1998, pp. III-7 to III-9.

S. Tan, Desney (Ed), Nijholt, Anton (Ed.). *Brain-Computer Interfaces: Applying our Minds to Human-Computer Interaction.* London: Springer, 2010.

Teplan, Michal. *Fundamentals of EEG measurement.* Measurement Science Review, Volume 2, Section 2, 2002. Bratislava: Institute of Measurement Science, Slovak Academy of Sciences, 2002.

Walter , W. G., Shipton H. W.. *A New Toposcopic Display System*. Bristol: Burden Neurological Institute, 1951.