Web-Mindscape and *REFLEXION – In Sync/Out of Sync* –: Biofeedback and Physical Computing in Inter-active New Media Art

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Abstract. The article draws attention to physical computing as a method for designing interactive biofeedback systems in New Media Art. *Web-Mindscape* and *REFLEXION – In Sync/Out of Sync* –, two biofeedback installations by artist Claudia Robles-Angel serve as examples. We briefly describe the artist's intentions and give a detailed report of the technical realization of both installations in the context of physical computing. From a scientific perspective of physical computing and interactive biofeedback installations, we touch upon combining art and research in the form of art-as-science.

Keywords: New media art · Biofeedback · Physical computing · Interactive systems · Art-as-science

1 Introduction

1.1 Biofeedback and Immersion in Interactive New Media Art

Biofeedback methods developed in the 1960s by psychologist Neal E. Miller is a process that consists of measuring physiological parameters from a subject, e.g. heartbeats, brainwaves, breathing or skin resistance. Such methods were introduced in artworks (specifically in music performances) in 1965 by Alvin Lucier with his composition 'Music for Solo Performer – for Enormously Amplified Brain Waves and Percussion' [12]. For this purpose, Lucier used equipment for Electroencephalography (EEG) that belonged to the US Air Force [8]. From then on, other artists followed, e.g. Richard Teitelbaum's 'Organ Music' and 'IN TUNE', both from 1968. In these works, EEG signals control voltages in Moog synthesizers. The usage of Biofeedback in the past fifty years "has experienced substantial change, due to the rapid evolution of new technologies in the same period. The consequence of this is that nowadays we can find in the market a wide range of small and wearable interfaces for affordable prices, including also self-built and open source" [12].

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Physical computing can be understood as a system design method which plays an important role in the development of artistic interactive biofeedback systems.

The immersive character of the two artistic works described in this article is related to what Schacher describes as: "being submerged or enveloped, usually in water. In media arts and theory this term has been extended to mean envelopment by mediated contents, be they visual, sonic, or sometimes tactile" [18]. Furthermore, Grau conceives it as a situation of presence: "The media strategy aims at producing a high-grade feeling of immersion, of presence (an impression suggestive of 'being there')". [19]. The concept of immersion in these artistic works is related to spaces that surround visitors/performers with sound and light, which create an audiovisual environment with which they can interact with their bio-signals by measuring their inner states through respective corresponding interfaces: BCI (Brain-Computer Interface; cf. Miranda & Castet 2014 [20]) and pulse sensors, which makes them feel mentally and corporeally involved. Furthermore, such combination of bio-signals within an immersive atmosphere accentuates the feeling of "being there" [19] and accordingly, it accentuates the feedback between the audiovisual environment and the internal emotional states of performers and/or visitors. Although our two examples *WEB-Mindscape* and *REFLEXION – In Sync/Out of Sync* – implement two different types of bio-signals, they both nevertheless share a clear immersive character for audiences and/or performers alike.

1.2 Physical Computing in Interactive Biofeedback New Media Art Installations

Physical computing has revolutionized interactive media art. Based on hacking ideas [17], the Italian Arduino boards and their accessories nowadays extensively offered by third-party suppliers enable an iterative and straightforward approach to interactive New Media Art projects [5]. The artistic use of special hardware and software, which have a connection to the physical world, is a core aspect of physical computing [2, 3]. This coupling is enabled typically with microcontrollers so that sensors detect and actuators respond and change parts of the physical world. At the same time, practical artistic aspects and the simple handling of inexpensive computer technology are basic concepts. A characteristic element of physical computing is the iterative tinkering[1] process as experimental prototyping [2, 3, 5], making realizing specific components for installations possible. Also, biofeedback needs specific sensors and fastening, for example, wearable devices and modules to transmit sensor data to other devices or software interfaces. Moreover, the Arduino boards control actuators like performative lighting and sound [6]. Hence, physical computing is ideally suited for artistic biofeedback installations. In the following sections, our focus lies on the description of artistic intentions and, in particular, the technical realization of Claudia Robles Angel's above mentioned two installations in which physical computing takes a significant impact.

1.3 *WEB-Mindscape* and *REFLEXION*: Artistic Intentions and Challenges

Artistic intentions in both biofeedback installations are based on the usage of the human body as a visual and musical instrument [12], in order to enhance the body's potential

[1] Tinkering in the context of physical computing means an exploring, trying and iterative approach using IT (esp. microcontrollers) to enable and stimulate artistic creativity [2, 3, 5, 15].

by perceiving it from a different perspective, which creates a new type of relationship between performers, space, audience and media technology. Both projects bring together various interests: in addition to sound art and its combination with visual media, the interest is in the impact of combinations of human emotions and physiological parameters on digital art. Her main aim is to create a new type of relationship between sound, architecture, light and human beings in a diversity of art situations, for example, interactive installations.

The creation of interactive biofeedback installations, which are different from performances, raises a challenge and the question about which interface should be used or developed in order to invite participants to create an audiovisual environment with their emotional states. Another challenge in using bio-signals in interactive installations is that interfaces for biofeedback usually require complicated methods to attach them to the participants (for example, gel for each electrode, utmost precision in positioning electrodes, etc.). So these interfaces are difficult to implement with large audiences of participants in interactive installations [13].

2 *Web-Mindscape* and *REFLEXION – In Sync/Out of Sync*: Brain-Computer Interface, Electrocardiogram, and Electroluminiscence in Interactive New Media Art

2.1 Web-Mindscape

Web-Mindscape is a interactive installation for brainwaves, light, sound and tweets using electroluminescent (EL) wires and a BCI. This installation joins diverse aspects, such as social networks, sound, brainwaves and visual elements. It creates a site-specific immersive audiovisual environment, where sound is diffused in surround, and the visual elements consist of light produced via electroluminescent wires (EL wires). Participants are immersed in a luminous structure, surrounded by light cables and sound, the latter diffused in eight audio channels, creating an immersive audiovisual environment.

Visitors are invited (one at a time) to interact with the audiovisual environment (light and sound) by using a BCI interface, which measures their brain activity. Thereby, they are confronted with messages from a social network (Twitter) worldwide. Simultaneously, the worldwide community is invited to join an additional Twitter account. All these tweet messages are turned into an audible sound. After that, the computer measures the visitors' cerebral activity and analyses their emotional reactions to the environment and the tweets. This data is transformed into visual and audible signals, which reproduce how the inner of the subject is influenced by the outer environment, while impacting the installation's audiovisual environment.

This work was developed and firstly exhibited during an artist in residence in in 2016 thanks to a grant offered by the IK foundation in Stichting/The Netherlands. The current version was presented in May and June 2017 at Harvestworks – Digital Media Arts Center in New York City for three days, added to two full days at the ISEA 2017 – International Symposium on Electronic Art in Manizales, Colombia (Fig. 1).

Fig. 1. *Web-Mindscape* at ISEA 2017, Manizales, Colombia. ©Claudia Robles-Angel/VG Bild und Kunst. Photo: Image Festival Manizales. See also https://vimeo.com/225400078

***Web-Mindscape's* Brain-Computer Interface: EMOTIV**

Previous works of Claudia Robles-Angel in physical computing used the open-source EEG interface from Olimex [11], and other commercial BCI headsets were used in the work of other artists. *Web-Mindscape uses* the EEG interface EMOTIV *Insight*. This interface is developed for health and well-being purposes which consists of five polymer sensors that absorb humidity from the air, thus in opposition to the Olimex, does not require the application of gel or saline solutions and is therefore suited well for usage in art installations. On the other hand, this interface does not work as accurately as the types discussed above. However, the EMOTIV *Insight* is connected via Bluetooth to the computer and has software that helps the user check the connection of the electrodes to the scalp during the set-up process (see Fig. 2).

In order to send values from the BCI interface to MAX (an audiovisual and object-oriented software by *Cycling'74*), which is responsible for the audiovisual environment, it is necessary to find additional software to read and translate raw data from the interface. After exploring several possibilities, the software *MindYourOsc* was selected, which divides the EEG data into five basic emotions: Engagement/Boredom, Frustration, Meditation, Excitement and Excitement Long Term. Although these five emotions are used at the start of the development, test persons could not entirely understand how their brain activity influenced the audiovisual environment. For this reason, the set is reduced to only two emotions: Meditation and Excitement, inviting in this way visitors to participate by controlling the interactive space with these two opposite emotions [13].

***Web-Mindscape*'s Visual Environment**

A light structure made by electroluminescent wires (EL wires) creates the visual environment. This wired structure is set according to the characteristics of the installation space (i.e. adaptable to different venues, provided it is dark). The data of a subject's brain waves from the BCI interface turn on/off different cables and in different tempos depending on the two opposite emotional states using MAX.

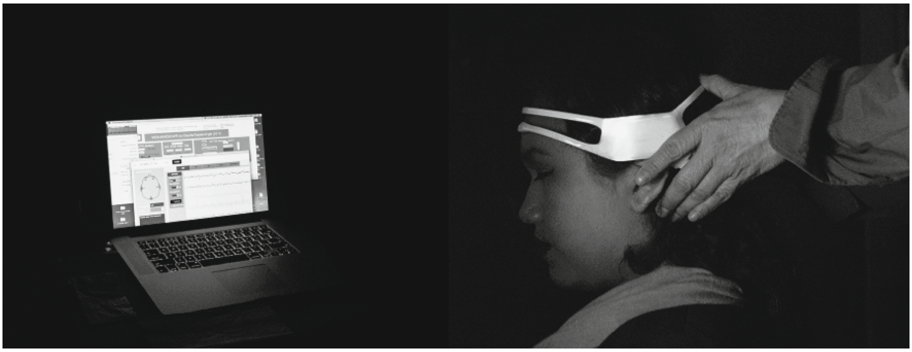

Fig. 2. EMOTIV software during the set-up process.

A ready-to-use solution for remote controlling the two 16 EL wires of 3 m each and two ELs of 25 m (34 wires and about 210 m in total) via MAX is unavailable. Thus, appropriate prototypes had to be developed in order to fulfil such artistic intention. In particular, the frequent activating of different wires, which results in various lengths of constantly glowing cables, was a challenge. A solution had to be found in an iterative tinkering process so that a realization based on Arduino boards was developed in the context of physical computing. Firstly, different serial values corresponding to the smooth dynamic states of the installation were generated in MAX and then sent via a virtual serial interface to the USB port of the host computer. Finally, two (resp. three) boxes connected to this USB port were created for the EL-control, each with a shield tower consisting of an Arduino-Uno board, two custom-made intermediate boards for adaptation and two optocouplers Escudo-Dos shields by *Sparkfun*, which drive the EL wires via triacs (see Fig. 3). Additionally, DC resp. AC to AC converters, also called as EL-inverters were used to power the EL wires with the required high AC voltage. Since there were no inverters available at the time of development that could supply such a wide range of resulting cable lengths, four of them were installed per box, so each were assigned to a group of four wires (see Fig. 4). Therefore, the Escudos had to be rebuilt to be in a position to control several inverters.[2]

Web-Mindscape's Sound Environment

The sound section of the work consists of a surround soundscape (eight independent audio channels), which changes depending on the information coming from the visitor's EEG.

There are two primary sound sources. the first is a balanced and subtle soundscape composed of frequencies from the brain waves combined with a field recording, which is activated when the participant is relaxed. The second source is the sound conversion of texts sent via Twitter, which are converted into sound by a text-to-speech algorithm inside the MAX patch. Once converted, this synthetic voice is used as sound material to which diverse sound effects are applied, such as, for example, Granular synthesis.

[2] Modern types of inverters are available that can partially handle such a bandwidth as well provide a stable output voltage. The current version of the *Web-Mindscape* boxes is equipped with these newer inverters.

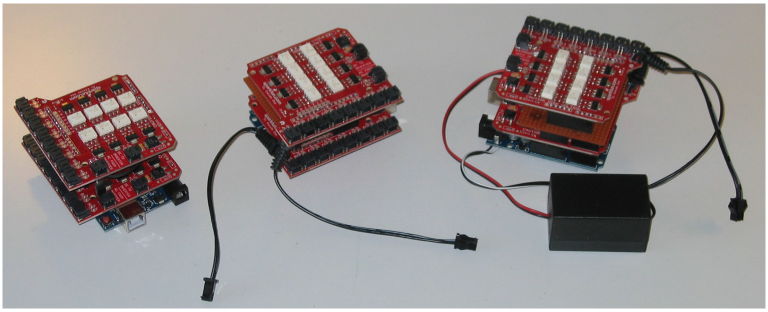

Fig. 3. Arduino Uno boards with shields used in *Web-Mindscape***.**

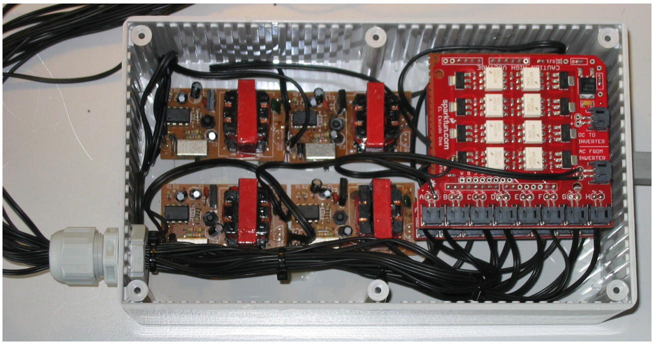

Fig. 4. One of three EL-wire control boxes with Arduino, shields and inverters.

The subject's brain activity modifies the parameters of the sound effects, and this sound is activated when the subject's relaxed condition is altered (Excitement state), which creates a sonic environment made of words as whispers, and which increases its level of complexity in a degree dependent on the data received from the brain activity.

2.2 *REFLEXION – in Sync/Out of Sync –*

REFLEXION – In Sync/Out of Sync – is an interactive installation (with an additional performance) consisting of (EL) wires and octophonic sound, in which visitors are encouraged to create together a light environment. Inspired by *Polytopes* [14] by Iannis Xenakis, the installation explores the relationship between sound, light, color and architecture with a different element, i.e. the interaction between individuals and their emotional and physiological reactions which impacts the sound and light of the installation. As with *Polytopes*, the space is fully integrated with the musical part, in which two visitors at a time are sitting next to each other are invited to create a musical and visual environment of sound and light with their inner (heartbeats) biological rhythms together.

In this manner, two visitors are invited to sit next to each other surrounded by a light structure made of EL wires steered by their heartbeat via a finger pulse sensor. The purpose of this project is, on the one hand, to make visible unconscious internal reactions that are produced in a subject in a simple situation such as sitting next to another human being; on the other hand, the project serves the purpose of inviting people to be aware of their inner-self and of the other person, as well as of their environment.

Sound and light structures are created according to the structural/architectural properties of the space: while the sound utilizes the acoustical characteristics of the space, the light structure on the other hand, reflects the shape of the space on the surface. The project does not only consist of an interactive installation combining sound and light, but it also includes a performance using the same central core principles.

The sound and light structure is based on the *Out-of-Sync/In-Sync* concept: when the two participants do not share the same rhythm of their heartbeats, the installation/performance is in an *Out-of-Sync* state; however, if the frequencies of the heart rates of the two participants run synchronously, the installation is in an *In-Sync* state and the sound and light events of the project change accordingly. This principal concept is based on research showing that our heartbeats can be synchronized by deepening the perception of others [7]. The Premiere of *REFLEXION – In Sync/Out of Sync* – took place at *Kunststation Sankt Peter* in Cologne/Germany in 2019, supported by *Innogy Stiftung* and *ON Neue Musik*. Further presentations followed in Cologne and at the *MM Gerdau Museu das Minas e do Metalin* in Belo Horizonte/Brazil in 2020 and in Bonn at *Dialograum Kreuzung an St. Helena* in 2021 (Fig. 5).

Fig. 5. *REFLEXION – In Sync/Out of Sync* 2020 –. Museum Gerdau Belo Horizonte. ©Claudia Robles-Angel/VG Bild und Kunst. Photo by Lucas D'ambrosio. See also https://vimeo.com/379450289

REFLEXION's Pulse Sensors

Because heart rates and pulse rates are identical, the suitable biosensor for this project is a finger pulse detector, which can be quickly and easily attached to each participant without much guidance avoiding the inconveniences of using an ECG (electrocardiogram) sensor, which would require to be attached to the thorax, needing constant supervision.

Hence, both the pulse sensors and the lighting control can be considered physical computing projects specially developed and assembled for this installation. This is because there are no ready-to-use commercial pulse sensors with an open standard regarding raw data, so solutions in the context of physical computing acquire relevance.

Concerning the software, the Pulse-Sensor library by Joel Murphy et al. [10] provides a basis for the Arduino sketch. The voltage coming from the sensor is analyzed, and a person's heart rate is calculated over several measurement intervals. These values are sent as serial data to the host computer and processed by different algorithms written in the MAX software, where suitable serial values are then sent to the lightning control boxes for the rhythm of the light environment. The light installation reacts, therefore, in real-time according to the participants' pulses.

Regarding the hardware, an amplifier board and fingertip by Easy Pulse (Embedded Lab) were selected for each of the sensors [4]. After a few attempts with various DIY sensors that follow the principle of photoplethysmography (PPG), the Easy Pulse sensors were convincing in terms of precision, ease of wearing and handling. In addition, Arduino Uno resp. Nano boards are used. These are connected wirelessly via Xbee modules to the host computer so that free moving space is possible for the installation and the performance.

Testing out the components, their interaction, the adaptation and the assembling was an iterative tinkering process that culminated in a first Arduino Uno version fed with a standard battery and a later, small-sized Nano version. An external mini power bank energizes this version, and it is optimized in battery life and wearability for the performance (see Fig. 6).

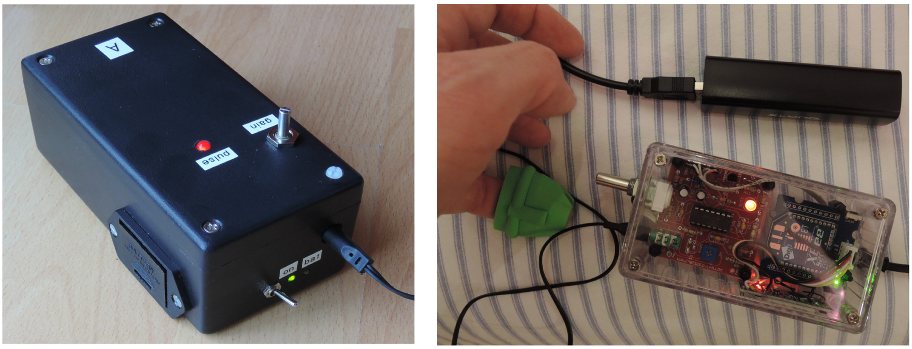

Fig. 6. Two versions of the assembled PPG sensors.

***REFLEXION*'s Light Structure**

The light structure consists of EL chasing wires, a special type of EL wires that provide an apparent uninterrupted light movement. This motion is intensified or reduced in consonance with the heartbeats when in the 'unisono' state. By this means, visitors are invited to be mindful of their surroundings: fellow human beings and the space itself. Hence, the data of the heartbeat/pulse of the two visitors are used in order to turn on/off different cables in different frequencies, creating different tempos and rhythms.

In the *Out-of-Sync* state, the asynchronous heartbeats and the inharmonic noises of the EL cables cause the light structure to flicker. When both heartbeats are, however, synchronized (In-Synch state), the light structure becomes stable (no flickering), and the roof structure of the space is reflected on the floor.

Based on the experience in *Web-Mindscape*, the physical computing components Arduino and Escudo Dos are used for the EL lightning control too. The chasing effect arises because each chasing cable consists of three thin EL wires plated together and light up one after the other. The faster the three wires are switched, the faster is the flowing/chasing impression. That means that three Escudo-Dos channels are required for each chasing cable. In this manner, for a total of 12 distributed cables, four control boxes with Arduino Uno and Escudo Dos shields are assembled. The boxes are connected with modern external inverters with a stable output of high AC voltage, which guarantees a safe operation during the installation and performance. Additionally, in practice, the JST PHR connectors of the chasing cables are very prone to failure. Therefore, all chasing cables and control boxes are equipped with stable Renk DIN plug connections suitable for continuous operation during the whole exhibition (see Fig. 7).

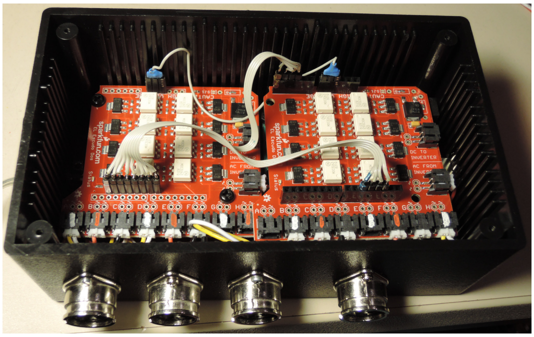

Fig. 7. One of the chasing control-boxes with Arduino Uno and two Escudo Dos boards.

***REFLEXION*'s Musical Components**

The musical components of the project consist of two sound elements:

1. After the pulse sensors read the frequencies and rhythms of the heartbeats, they are transformed using sound synthesis and sound design treatments with MAX.
2. Light cables and their circuit boards produce noise, mostly high frequencies, which were recorded and used with additional DSP functions in MAX.

When the installation is in the *Out-of-Sync* state, the sound behaves as follows: the asynchronous heart rates and the electrical noises of the light cables create a sound environment of restlessness in which inharmonic or dissonant sound constellations are dominated. However, during the *In-Sync* state heartbeats are brought into unison. So the sound and the light structure produce an environment of restlessness and harmony. Thus, harmonic and consonant sound constellations create a meditative space.

The acoustic properties of the space play, therefore, a particularly relevant role. As they are incorporated in the immersive sound conception through sound projection via eight loudspeakers, loudspeakers are distributed accordingly in the space depending on its particular acoustics.

3 Summary and Future Perspectives

We pointed out the importance of physical computing for interactive biofeedback installations in New Media Art by referring to *WEB-Mindscape* and *REFLEXION – In Sync/Out of Sync* – and by describing the artistic ideas on which both installations are based. Moreover, this article focuses on the application of physical computing by given detailed descriptions of the technology involved.

As an essential future perspective, we want to point out that physical computing represents an intersection for an art-related, expanded research term, in which "research through art" and "research in art" come into focus [5, 9, 15, 16]. At the same time, this leads to a scientific attitude that propagates a heuristic, artistic and – as typical in physical computing – iterative approach described above. This approach enables and encourages the further finding of theses and associated methodologies[3].

Especially installations with biofeedback offer the opportunity to involve them in scientific investigations as part of field studies, such as music research or research on human-machine interaction's social and artistic aspects. On the one hand, these installations are based on interactive processes, a core interest of scientific discussions in recent years. On the other hand, they can serve as a laboratory or test field for specific methods or the development of methods. Biofeedback data can be recorded and – e.g. in combination with structured observation [1, 5] – be evaluated and analyzed. According to our previous research, engagement and attention are important aspects in artistic human-machine interaction and can be observed concerning their duration, to physical expression and to biological data. For example, the presentation of one of the installations portrayed in this article included additional recordings with infrared cameras. The extensive evaluation of all the data is currently under development and will be discussed in a future publication.

To summarize, in the context of art-as-science, applied physical computing in connection with biofeedback systems is an artistic practice and an artistic extension. It invites researchers to a discerning reflection on creative new media technology and scientific exploration of embodiment, situatedness, and different kinds of interaction (e.g. Dautenhahn & Saunders 2011 [21]; Miranda 2014 [22]). Such research gains new insights into human interaction regarding this technology and the underlying psychological and mental mechanisms. In particular, a deeper understanding of the complicated processes underlying the interactive behavior patterns of humans in an artistic context will be investigated in the future [5, 16].

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