An approach to Generative Art from Brain Computer Interfaces

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Abstract

Nowadays, technological advances have influenced all human activities generating new dynamics and ways of communication. In this context, some artists have incorporated these advances in their creative process, giving rise to new aesthetic expressions that are referred in literature as Generative Art, which is characterized by assigning a certain part of the creative process to a system that acts with a certain degree of autonomy [1]. The most recent works in generative art show the importance of the visual component as well as the artist's effort to provide the viewer an active role in order to offer a captivating experience [2]. In this regard, this work proposes a computational system for the creation of generative art that explores the use of a Brain Computer Interface (BCI), which allows the materialization of the captured data of the spectator's brain activity in a digital artwork. In this way, the spectator takes an active role in the creative process. Additionally, the proposed system makes an audible representation of the user's mental states materialized in an artistic piece as a complementary part of the artwork. The generated work takes advantage of concepts of geometry, color and spatial location to graph the visual space and uses the cerebral signals as random and recursive elements that give complexity to the autonomous construction. As an added value, visual production is accompanied by a musical piece generated from the BCI data, which complements the created artwork providing a bimodal communication character.

1. Introduction

The technological boom experienced since the end of the 20th century, in which Information Technologies have permeated almost all human activities, has generated new dynamics and forms of development and communication. Consequently, in the context of Art, some artists and creators have incorporated these advances into their creative process, giving rise to new aesthetic expressions such as electronic art, computational art and others.

These new forms of expressing art are referred to in the literature as generative art, whose fundamental premise is based on the fact that part of the creative process is carried out by a system that acts with a certain degree of autonomy, but keeping elements such as (color, form, space, texture, etc.) and principles (balance, movement, proportion, uniqueness, etc.) of art [1][3][4].

In works such as [5][6][2][8] the importance of the visual component in generative art is evident, as well as the concern that the work responds to certain interactions of the spectator. These proposals demonstrate the artist's effort to provide the viewer with an active role and a captivating experience. However, in offering the possibility of interaction with the work, it is important that the artist contemplates multiple ways of communication since, although vision is a fundamental element of perception, multimodality offers a more complete way of communication, taking advantage of other senses (such as the auditory) to create a more meaningful experience for the audience.
In this context, the fundamental premise of this proposal is to extend the capacity of interaction of the audience and more than the artwork adapts to actions executed by the spectator, it proposes to offer the spectator a participative and immersive experience in the creative process.

To achieve this purpose, a bibliographic review was carried out in search of technologies that would allow data from the spectator to be captured and used in the creative process. As a result of this effort, a new and rarely used alternative in the context of generative art was found in the Computer Brain Interfaces (BCI).

The next section presents the BCI concept, its possibilities and the selected device. In addition, some concepts related to music are presented, which were taken into account for the creation of the musical piece that accompanies the artwork that is also generated from data from brain activity.

2. Brain Computer Interfaces

Brain Computer Interfaces are hardware and software communication systems whose purpose is to help the user interact with the external environment by predicting their intentions based on data related to their brain activity.

These types of systems have been fundamentally studied and used as assistance tools for people with reduced mobility because they do not involve the use of muscular channels for the user interaction [9].

A BCI device captures signals from the brain and can perform certain calculations following five consecutive stages: Signal Acquisition, Signal Pre-processing, Feature Extraction, and Signal Classification.

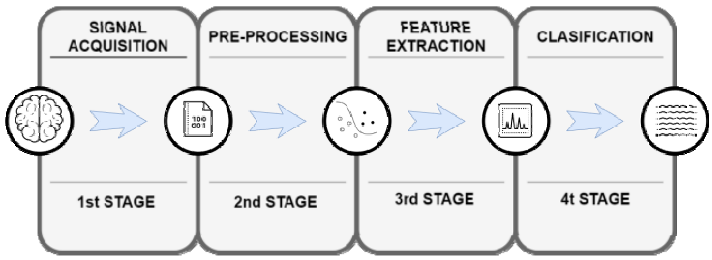

Fig 1. BCI. stages

In this way, a BCI device allows the brain to communicate with external mechanical devices and involves important aspects such as voluntary control of electroencephalographic signals, synchronization of brain rhythms and the measurement, interpretation and classification of neuronal activity. This last aspect is the one that is taken as base on this proposal

2.1 Brainwaves, Classification and Capture Devices

Brain waves are produced when brain cells (neurons) are activated and produce local current flows that are translated into electrical impulses and changes. Encephalography or EEG primarily measures the currents flowing during the synaptic excitations of the dendrites of many pyramidal neurons in the cerebral cortex [10].

Brain patterns form sinusoidal graphs that commonly range from 0.5 to 100 μV in amplitude, that is, almost 100 times less than ECG signals (electrocardiograms). The Fourier transform allows these raw signals to be taken and amplified to obtain a higher volume of information. Brainwaves are measured in cycles per second (Hz), the higher the number of Hz, the higher the frequency or brain activity. The first approach to brainwaves was made by the German Hans Berger in 1924 [11]. Between 1930 and 1940 the brainwaves were classified in 5 groups which are summarized in Table 1 [11]:

Waves	Ranges	Mental States
Delta (δ)	< 4 Hz	Unconsciousness, deep sleep.
Theta (θ)	4Hz - 8Hz	Relaxation, intuition, creativity, remembrance, Imagination.
Alpha (α)	8Hz - 12Hz	Mental effort, sleepless relaxation, stillness, awareness.
Low Beta (β)	12Hz - 15Hz	Relaxation and focus.
Mid Beta (β)	16Hz - 20Hz	Thinking, self-consciousness.
High Beta (β)	21Hz - 30Hz	Alert, agitation, disturbance.
Gamma (γ)	30Hz - 100Hz	Motor functions and high mental activity

Table 1. Brain Waves and their classification.

According to the above, a BCI device allows inference to be made about an individual’s mental state (attention level, relaxation) and some of his motor functions. In recent years, manufacturers such as Emotiv (EPOC), Neurosky (Mindwave) and OpenBCI (Cyton) have been dedicated to the development of non-invasive BCI devices, which allow the capture of brain signals in an easy and user-friendly way.

For the purposes of this paper, the Mindwave device was chosen because of its economic affordability, reliability in the delivery of data related to the user's mental states, ease of use and the comfort the user feel when interacting with the device, as evidenced in the study conducted in [12].

3. Music: Basic concepts

The word 'music' derives from the Greek mousike (μουσική) which means "art of the muses" [13]. According to [14] music is "the art of combining vocal, instrumental (or both) sounds to produce beauty of form, harmony, and expression of emotion. Also, according to modernist composer Edgard Varèse, music is defined as "organized sound"[15]. However, many authors have expressed different opinions about what is or is not considered music. Therefore, in order to better understand the definition and language of music, it is necessary to become familiar with concepts such as: tone (height), duration, intensity, and timbre [16].

Tone is an essential characteristic that allows us to distinguish between high-pitched and low-pitched sounds [17]. The frequency of each sound - usually measured in Hertz (Hz) - denotes the number of sound waves per second and allows identifying the musical note to which it corresponds.

Duration is the time in which the vibrations produced by a sound are maintained, that is, the period or interval of time in which a specific note sounds [18]. The graphic representation is made by means of musical figures assigned to different sounds, where the semibreve is the reference unit and each subdivision (musical figure) lasts in time the half of the previous note.

Intensity, also known as 'volume', is the property that allows you to identify how loud or soft a sound is perceived. Volume levels are measured in decibels (dB). The range of human hearing lies between 0 and 120 dB approximately, for this reason, sounds above the upper limit - such as that produced by aircraft take-off - can cause irreversible damage to hearing. While frequency is set by the length of the sound waves, intensity is determined by its height, which can also be called the wavelength [19].

Finally, the 'timbre' is an intrinsic property that allows the human ear to differentiate between sounds emitted by various sources, even when they do not belong to the same category. For example: the sound emitted by a guitar and an electric bass or the same musical note played by different instruments. Each of the above definitions constitute the structure and foundation of what we know as 'music'.

4. Proposed system: Early stages

Tests were carried out with different colors and geometric figures, so that substantial improvements could be evidenced at each stage. In this way, the final proposal exhibits an improvement in the robustness of the algorithm and the resulting images. Next, the experimental process is described: To generate generative art, *Processing* was used as a programming environment. In the same way, an exploration of the geometric forms that have more relevance and that are more easily identifiable in nature and in daily life was made. This, in order to the aim for the naturalness of the generated piece.

Some of the geometric figures chosen were hexagons, triangles and circles, however, the experimentation was carried out with circles because the low computational complexity required to create them allows the inclusion of different characteristics in the final piece. The first approach came from the hand of a mathematical function whose curves are shaped like the flower's petal. This function is called "*Rhodonea Curve*" or "Rose curve" and was named by the Italian mathematician Guido Grandi between 1723 and 1728. It allows drawing roses from polar coordinates. Figure 1 describes the function, expressed in polar coordinates and its representation in parametric equations:

$$r = \cos(k\theta)$$

$$x = \cos(k\theta)\cos(\theta)$$

$$y = \cos(k\theta)\sin(\theta)$$

Fig 2. Polar coordinates and parametric equations.

If k = n/d, then the figure will change due to the values of these variables, in other words, the visual representation of the figure will have a greater or lesser number of petals.

Figure 2 shows the curves defined for different values of n and d.

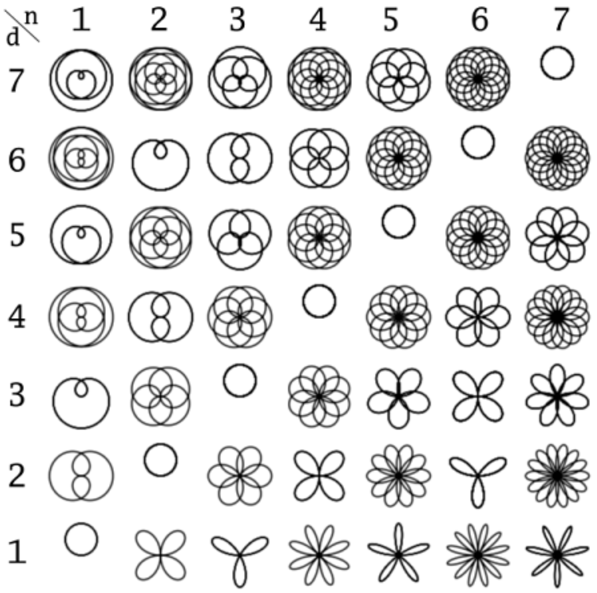

Fig 3. Rose Curves with different values of n y d.

The second approach continued under the premise of using circles for the construction of the final piece. In this regard, color and spatial location were adopted as characteristics of generative art, so a variable associated with color and a pair of coordinates for the location of the figure were introduced as random elements.

Circles are formed by lines starting from a specific position. The algorithm performs a cycle from zero to 360 degrees for the creation of a circle. Within it, a straight line is constructed whose values of X1 and Y2 are calculated by random numbers between 50 - 150 and 150 - 360 respectively. The values of X2 and Y1 are both zero. In this way, the centre of the circle varies and its internal points are defined, as can be seen in figure 4:

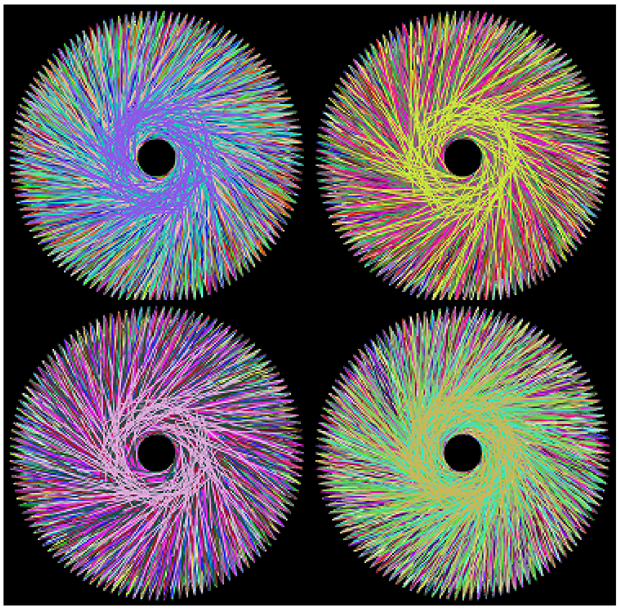

Fig 4. Multicolor circles generated randomly.

5. System's description

Figure 5 shows the architecture of the application, which depicts how music and generative art come together in this proposal.

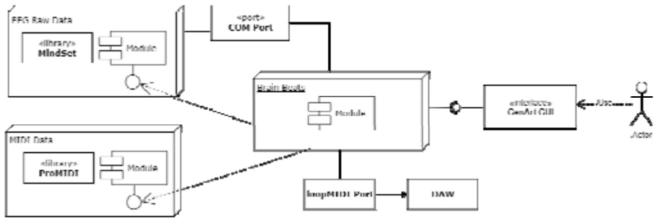

Fig 5. App's Architecture.

The results obtained, contributions, and possible applications of this work in the context of music generated from brain activity are described by the author in [20].

Regarding generative art, the third approach — and the one that represents the current version of the system — gathers the ideas introduced in the previous stages, however, instead of randomizing the whole algorithm, it takes as input the values of the brainwaves provided by the user who interact with the device, in order to produce art through brain activity.

Figure 6 shows some examples of the spectator's experiences and the works of art created by their own brain data.

Fig 6. User interaction

The application's functioning will be explained shortly. It begins with the definition of a variable that will measure time in milliseconds, this variable will be used to provide continuity and movement to the final piece generated. A seed is also defined for the random values of the algorithm.

For this approach, the values of the five brain waves are used: *delta, theta, alpha, beta and gamma*.
Initially, the raw data sent by the device are not used, but for each of the wave values, a data pre-processing is carried beforehand, so that these can be used by the algorithm.

Regarding *Alpha* waves we distinguish two types of values: The common ones, which are in a range of 8Hz - 12Hz and the so-called *High Alpha* which are between 10Hz - 12Hz.

Continuing with the idea of using circles, two models are proposed: The first is a training set consisting of *Delta*, *Theta* and *Alpha* waves that will control the number of circles in the piece. We will call this set *C1.* The second set (*C2*), consisting of *High Alpha, Beta* and *Gamma* waves will be used to control the radius of each circle in the scene.

An additional variable that takes the value of the screen width and divides it by the value of the brainwaves in *C2* is used. This, in order to graphing the circles generated within the display area. It then iterates from zero to the value of the brainwaves in *C1*.

Three new variables are introduced: The first two are the coordinates X and Y, whose values will be the multiplication of the previous variable times a random value between zero and the value of the brainwaves at *C1* plus one.

The third variable is responsible for the displacement of each circle in the figure, so it will take the time variable introduced at the beginning and multiply it by a decimal number between 0.1 and 1, times the number 60 times a random number between zero and two.

The mentioned values were set after testing and observing that they made possible the perception of movement.

Each circle moves in one of the two axes, following a straight line whose sinusoidal displacement and wavelength vary randomly.

The color of each circle and its interpolation with the following color are chosen in the same way, for that purpose, the device's attention and relaxation values are used to choose, randomly, the opacity of each circle present in the piece, which varies in a range that has the user's attention level has as its lower bound and its relaxation level as its upper.

6. User tests and

Brainwaves exploration

In order to ensure variability and expressiveness in the final piece, it was necessary to determine which pair of waves from sets *C1* and *C2* would be selected. These are shown in Table 2.

***C1*(Number of circles)**	***C2*(Radius)**
Alpha	High Alpha
Theta	Beta
Delta	Gamma

Table 2. Training sets.

Thus, tests were carried out with 6 users, which generated pieces showed divergent behaviors. Each user presented different mental states and a different production of brain waves.

As will be shown in the figures, the brain waves of each user allow the creation of pieces of art with different morphological characteristics due to the quantity of variables that the algorithm gathers and that are expressed in an involuntary way. Similarly, the figures shown exhibit the uniqueness of each of the pieces. The geometric figures that are formed contain a series of basic design concepts such as: translation, superposition, gradation of shape, size, color and scale.

The variation of the opacity of the geometric figure along with the gradation of scale generates a controlled chaos effect, as well as the visual weight and the cognitive load of the piece that is being built it is modified as the interaction process with the BCI device lasts longer.

The different pieces generated are explained in detail below, taking into account the brain waves and the users who participated in the test:

User 1: Alpha - High Alpha.

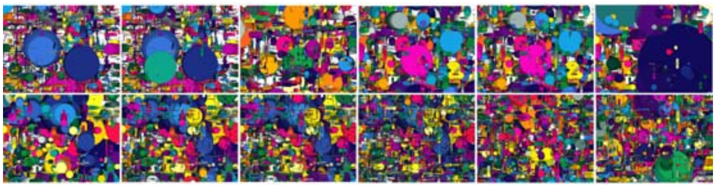

Fig 7. User 1 (Alpha – High Alpha).

As seen in the results, for these brainwaves, a grid of superimposed circular shapes with size gradation is created. The randomness of the position of the figures ends up being recurrent in the sense that a certain order is appreciated in the X and Y axes, as well as the distribution of the filling colors through all the composition.

User 2: Theta – Beta

Fig 8. User 2 (Theta – Beta).

These brainwaves, unlike the others, do not saturate the composition of images, leaving blank spaces that allow the image to breath, the figures tend to group in certain positions, which causes a certain visual imbalance in the results.

User 3: Delta - Gamma

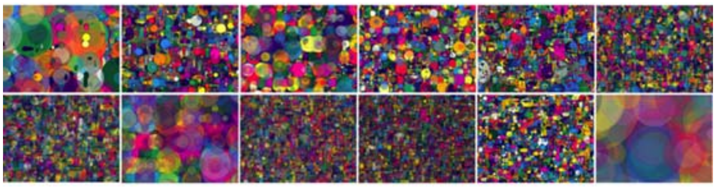

Fig 9. User 3 (Delta - Gamma).

With these brainwaves the figures are grouped massively throughout the composition, this generates a grid of superimposed circular shapes that vary with the opacity.

Regarding the mental states of the users, it was found that each one experienced different sensations, prior to the interaction with the BCI device. Thus, user one was sleepy at the time of the interaction, while user two was attentive – expectant. On the other hand, user three was relaxed.

In this regard, not only the values of the brain waves of each individual provide variability to the generated piece, but also, their mental states are a great input in the construction of the final piece.

Based on the information provided by the previous figures, it was decided to select the Delta - Gamma waves, since they are the pair of brain waves that provided more expressivity and variability.

This decision is also supported by the fact that these brainwaves are the ones in a lower and higher frequency range respectively, as show in the study carried out by [21] and the figure 9. The above is reflected in the fact that having fewer circles that quickly change its size brings more contrast, variability and expressiveness into the final piece.

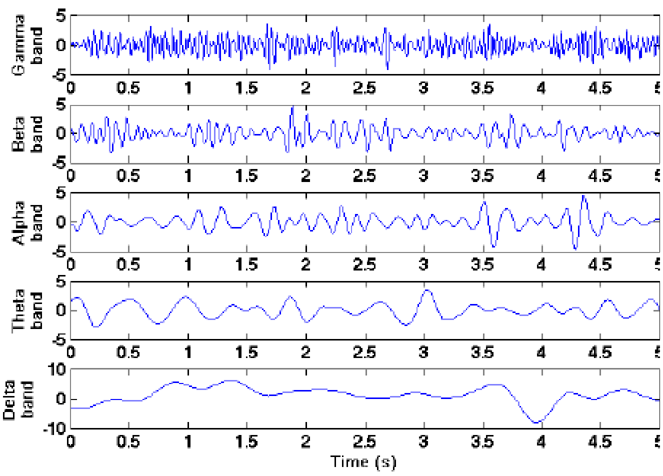

Fig 10. EEG brain frequency chart.

The figures below show tests performed on three different users in order to obtain the values of their Delta - Gamma waves to produce generative art.

User 4: Delta – Gamma

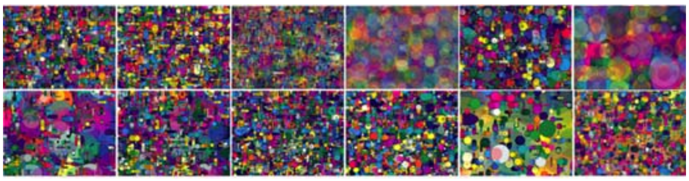

Fig 11. User 4 (Delta - Gamma).

With these brainwaves it's easy to observe gradation of color, translation of forms and interlacing of figures. It is important to see how the figure also presents a change in opacity which generates a diffuse image.

User 5: Delta – Gamma

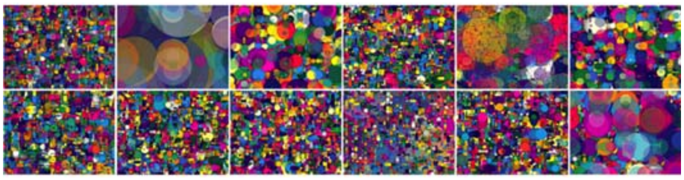

Fig 12. User 5 (Delta - Gamma).

The reticular organization using these brainwaves is clearer, since the size of the figures is smaller which contributes to a more logical order in the arrangement of its elements. There are certain moments when opacity, in conjunction with scale, blurs the composition, however, it tends to be homogeneous.

User 6: Delta - Gamma

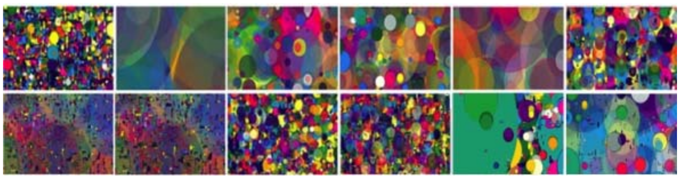

Fig 13. User 6 (Delta - Gamma).

The tendency of this type of brainwaves is to form lattices of circular superimposed forms, however, there are certain moments where there is variation of opacity and scale that produce visual asymmetry regarding the sizes of some figures with respect to others.

The tests performed and figures *7 – 9* and *11 - 13* shown above were run and captured in the same time frame for each user (one minute). This allowed us to obtain greater accuracy in the data and images presented.

In regard to the tests carried out with users whose brain waves used were different, it was found that the variability of these and the profile of the users allowed obtaining diverse results, as shown in *figures 7 - 9.*

Similarly, each of the pieces generated by the users presented different images, color patterns and compositions, even if the tests were performed with the same brainwaves (Delta - Gamma), as evidenced in figures *11 - 13*. This generates a composition with depth, whose randomness provides unique pieces considering that although the same waves and capture times are measured, the results of the images will be diverse.

The amalgam of each of the previous elements and their interrelation provide the necessary inputs that allow the creation of a piece of generative art that is not only based on the brain activity of a person, but also fluctuates with it, so that, at first, none of the images generated by users are the same, since their mental states and / or brain activity vary constantly.

7. Conclusions

During the experimentation it was found that, at in the beginning, some shyness was observed in the user - spectator due to the use of the BCI device. Nevertheless, once the creative process begins, there is evidence of an immersion and capture of the interest of the person, not only because of the visual feedback, but also because of the auditory one.

The system generated and the incorporation of BCI technologies allow to bring the user closer to art. In this regard, the result of this research does not propose to turn users into artists, but to obtain an artistic result that the user can create involuntarily. Thus, the BCI device is configured as a facilitator and mediator of this creative process.

The values obtained as a result of capturing the user's brainwaves offer enough randomness to make the algorithm produce a piece of art that is different for each viewer because it is linked to the user's brain activity.

The BCI captures information that allows to reassure the autonomy of the algorithm in the generation of the piece of art because the data with which this the piece is created are taken from the brain activity of the user, which is intangible for him. This means that the user is not aware of generating a certain effect in order to manipulate the artwork. He could not, for example, take explicit control over the way in which the parameters in the algorithm are reflected in the piece, but rather the piece reacts to its mental states and to the outcome of its brain activity. This is why, in the interaction, the user does not have total control over the final result of the work or what it produces, but somehow the user’s brain activity is reflected in an artistic piece. In this sense, during multiple tests, one of the users stated that, when concentrating, he could vary the size of the circles or the composition of the figure, however, this corresponds merely to a subjective perception of the person.

References

[1] P. Galanter, “What is generative art? Complexity theory as a context for art theory,” *6th Gener. Art Conf.*, p. 21, 2003.

[2] P. R. Jônatas Manzolli, “The Ode to Christus Hypercubus,” in *XXI Generative Art International Conference*, 2018.

[3] M. A. Boden and E. A. Edmonds, “What is generative art?,” *Digit. Creat.*, 2009.

[4] A. Dorin, J. McCabe, J. McCormack, G. Monro, and M. Whitelaw, “A framework for understanding generative art,” *Digit. Creat.*, 2012.

[5] P. K. Daniel Bisig, Martin Neukom, “Watchers – Directionality As Metaphor For Interaction With A Generative Installation,” in *XXI Generative Art International Conference*, 2018.

[6] S. O. Arne Eigenfeld, “MOMENTS: VR,” in *XXI Generative Art International Conference*, .

[7] K. Byers, “EMBODIED INTERACTIVE SOUND,” in *XXI Generative Art International Conference*, .

[8] M. Leggett, “Generative systems and the cinematic spaces of film and installation art,” *Leonardo*, 2007.

[9] L. & G. J. Nicolas, “Brain Computer Interfaces, a Review.,” *Sensors 2012, 12, 1211-1279; doi 10.3390/s120201211*, 2012.

[10] M. Teplan, “Fundamentals of EEG measurement,” *Meas. Sci. Rev.*, 2002.

[11] R. Jung and W. Berger, “Hans Bergers Entdeckung des Elektrenkephalogramms und seine ersten Befunde 1924-1931,” *Arch. Psychiatr. Nervenkr.*, 1979.

[12] F. RODRIGUEZ CARRILLO, Paola Johanna; JIMENEZ BUILES, Jovani Alberto; PATERNO, “Monitoreo de la actividad cerebral para la evaluación de la satisfacción,” *Rev. Ing. [S.l.], n. 42*, pp. 16–22, 2015.

[13] H. G. Liddell and R. Scott, *A Greek-English Lexicon with a revised supplement*. Oxford University Press, 1843.

[14] R. Allen, H. Fowler, and F. Fowler, “The Concise Oxford dictionary of current English,” *Oxford Clarendon Press*, 1990.

[15] R. F. GOLDMAN, “REVIEWS OF RECORDS,” *Music. Q.*, vol. XLVII, no. 1, pp. 133–134, 1961.

[16] R. D. Patterson, E. Gaudrain, and T. C. Walters, “The Perception of Family and Register in Musical Tones,” in *Music Perception*, 2010.

[17] C. Plack and A. Oxenham, *Pitch: Neural Coding and Perception*. 2005.

[18] B. Benward and M. Saker, *Music in theory and practice*. 2008.

[19] Michael Hewitt, *Music Theory for Computer Musicians*. 2008.

[20] R. Ricardo Andres Diaz, V. Javier Mauricio Reyes, and R. C. Paola J., “Generando música a través de la Actividad Cerebral,” *Brazilian J. Dev.*, vol. 5, no. 6, pp. 5375–5388, 2019.

[21] M. Abo-Zahhad, S. M. Ahmed, and S. N. Abbas, “A New EEG Acquisition Protocol for Biometric Identification Using Eye Blinking Signals,” *Int. J. Intell. Syst. Appl.*, 2015.