Embodiments, visualizations, and immersion with enactive affective systems

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Embodiments, Visualizations and Immersion with Enactive Affective Systems

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ABSTRACT

Our proposal in Bioart and Biomedical Engineering for affective esthetics focuses on the expanded sensorium and investigates problems regarding enactive systems. These systems enhance the sensorial experiences and amplify kinesthesia by adding the sensations that are formed in response to the physical world, which aesthetically constitutes the principle of synaesthesia. In this paper, we also present enactive systems inside the CAVE, configuring compelling experiences in data landscapes and human affective narratives. The interaction occurs through the acquisition, data visualization and analysis of several synchronized physiological signals, to which the landscapes respond and provide immediate feedback, according to the detected participants’ actions and the intertwined responses of the environment. The signals we use to analyze the human states include the electrocardiography (ECG) signal, the respiratory flow, the galvanic skin response (GSR) signal, plantar pressures, the pulse signal and others. Each signal is collected by using a specifically designed dedicated electronic board, with reduced dimensions, so it does not interfere with normal movements, according to the principles of transparent technologies. Also, the electronic boards are implemented in a modular approach, so they are independent, and can be used in many different desired combinations, and at the same time provide synchronization between the collected data.

Keywords: Affective aesthetics, enactive systems, Bioart, immersion, data visualization, physiological sensors, cinematic floor.

1. INTRODUCTION

In the beginning, virtual reality systems for immersive experience used different types of proprioceptive devices and movement trackers to map a participant’s displacements or gestures and provide a feedback for navigation and positioning. This principle constitutes the basic idea of kinesthesia in the domain of aesthetics, which was largely explored in many applications in virtual reality.

Our proposal in Bioart and our research in Biomedical Engineering for affective aesthetics focus on the expanded sensorium and investigate problems regarding enactive systems. These systems enhance the sensorial experiences and amplify kinesthesia by adding the sensations that are formed in response to the physical world, which aesthetically constitutes the principle of synaesthesia. This approach relates the Kinetic Art of the 80s and the experiences in virtual reality with disruptive technologies\textsuperscript{1} for perception and sensorial measurement, offering a compelling experience in data landscapes for visualizing with the all the senses. The artworks of LART collection are now in the phase of expanding the sensorial apparatus in terms of physiological signals. The background of this investigation was published in the chapter ‘Human Biology,’ in the recent book.\textsuperscript{2} Simulators technologically

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add to the displacements the effects of collisions, vibrations, trepidations etc., when inhabiting synthetic spaces. Also, the historical intuitive interfaces, such as shutter glasses, data gloves, trackers, emitters, force biofeedback devices, joysticks, among others, are empowered by physiological sensors that capture physiological signals in order to enhance the immersion experience and make it more intense. The embodied experience then corresponds to a Spinozan body with the affective ability to communicate with the environment through the several measured signals. This body sends and receives data, as it exchanges energies and signals with the environment, in an enactive condition described by Varela et al. 

In this paper, we present enactive systems inside the Caves, configuring compelling experiences in data landscapes and human affective narratives. The interaction occurs through the acquisition, data visualization and analysis of several synchronized physiological signals, to which the landscapes respond and provide immediate feedback, according to the detected participants’ actions and the intertwined responses of the environment.

The signals we use to analyze the human states include the electrocardiography (ECG) signal, the respiratory flow, the galvanic skin response (GSR) signals, plantar pressures, pulse signals and others. Each signal is collected by using a specifically designed dedicated electronic board, with reduced dimensions, so it does not interfere with normal movements, according to the principles of transparent technologies. Also, the electronic boards are implemented in a modular approach, so they are independent, and can be used in many different desired combinations, and at the same time provide synchronization between the collected data.

In order to collect the signals while the participants live the immersive experience, we developed special support biomaterials, such as an insole made out of Brazilian latex. This is a biocompatible material that helps fixing the electrodes in the participants skin, without displacements during the experience and without risks of allergic or other undesired reactions. This is especially important for easily positioning the plantar pressure sensors, through an easy-to-put insole with the electrodes already fixed.

In this context, the human actions and interactions generate living maps, body narratives through enactions in an ouroboric perception corresponding to Gibson’s concept of ecological perception. In this work, our Laboratory of Art and TechnoScience (LART) at the University of Brasilia at Gama, in Brazil, intends to collaborate with discussions on embodiments, data visualizations and immersions with enactive affective systems, which echo the enacionist theory of autopoiesis and to the naturalization of the technologies.

The Cave Automatic Virtual Environment (CAVE) has important applications in biomedical engineering, body arts, product design and others. LART develops research on CAVEs applied to scientific visualization, coordinated by Prof. Dr. Carla Rocha, of Software Engineering and Prof. Mateus Miranda, Automotive Engineering. The appropriate use of specialized hardware, including accessories for virtual reality immersion, bring fundamental changes to industrial work methods, as well as for training techniques, entertainment, culture, art, and health. The application is expanded beyond art and entertainment, mainly in games studies, and it is applied to automotive and biomedical engineering. The Cave is also a special place for aero spatial Engineering training. In fact, the kinesthetic sensations replicate the sensation of displacement inside an automobile, as well as the sensations of vibration and vertical movements typical of a vehicle, different speeds, collisions, etc. These various conditions may be created by the system in terms of physical sensations and synthetic data provided by actuators, as well as by the biofeedback using breathing, heat, heart beats and other signals collected by our physiological sensors. For embodiment and aesthetic affective emotions inside the CAVEs, our systems configure compelling experiences in data landscapes, by providing human narratives in biocybrid spaces.

2. THE AFFECTIVE AESTHETICS AND THE ENACTIVE SYSTEMS: REENGINEERING REALITY

The affective aesthetic in the design of art interfaces dialogues with scientific and disruptive innovations considering the flesh apparatus as an intelligent system, linked to the whole cosmos. Beside the human body, all living system and natural and artificial phenomena laws of signals emitted are processed when computerized. Concerning bodily signals and bodily data, mind/brain play a central role through the sensorial physiology such as the software platform that regulates the flesh apparatus for the intelligent system involved in the holistic natural condition. The body as part of an enactive system evokes the expansion of the aesthetic dimension in previously manifestations of conceptual art, body art, and happenings with responses generated in symbiotic
zones with programs within “hermeneutic operations,” dealing with biological and physical laws, when code and facts are experienced in the intensity of the senses and the ability of data laws built into the system. In the field of endophysics, Rössler’s interfaciology points out what the Performative Science is.

Reaffirming the origins of the discipline Aesthetica, postulated by the German philosopher Baungartem in 1750, we propose embedded systems for synaesthetic experiences of enactive affective embodiments and the ability to perceive the world with the all bodily senses. Physiology and synaesthesia are the main topics for our microcircuits of sensors, designed in order to manifest feelings related to behavior in enactments to the environment and mutual influences.

Enactive systems are no longer machines, but complex systems, surpassing the human condition and limits of the mechanistic paradigm. We must delete this old classification and consider human/animals/environment as a complex, or living organism. The expanded sensorium trough physiological interfaces are in the fundamentals of our historical artworks and theoretical discussions. In 1997 we discussed in the Flesh Factor list of Arts Electronica Memesis Symposium.

When we are connected, our sensorial apparatus experiences a complex process of mutations, unpredictability, dissipations in a integrated sensorial circuit of “trompe les sens”). The interfaces are synthetic skins, and like skins they receive, process and give back to us new behavior patterns regenerating ourselves. What matters is the relationships existing between the several sources of information and what results from this dialogue. So, if we believe in the second natural environment, in networked artificial systems, the human body and cosmos is in a symbiosis with technological/artificial/natural life...physical/real and virtual/synthetic.

3. TRANSPHYSIOLOGY OF PASSION: FROM TRANS-E TO ECSTASY

The affective aesthetic is routed in the 1990s, when we started to postulate the interest of sciences on the human factor of technologies and the focus on Virtual Reality and sensorial apparatus was part of the investigation. We now propose the enactive affective systems expanded to biomedical engineering researches. In the domain of art and social sciences we highlight the specific context of Brazilian Culture and the concept of trance transposed to the ecstasy state following the contribution of the post doctoral studies of Maria Aparecida Donato at LART*. In our artwork inside the Cave we propose in Section 5.3 the analysis of rituals in the state of ecstasy, using biograms of corporeal living maps in kinestesia and synaesthesia as results of perceiving and processing data of human physiology. Our interested in other part of the research is the application for the understanding of sentences and meanings of body actions, and their cosmic relationship kinestemas and synaestemas that can be related to gestures, movements, speeds, rhythms in candombs’ rituals of Afro-Brazilian religions, and the popular folk manifestations such as the Brazilian performatic Carnival and samba. Bodies in a deep immersive state attempt the atmosphere for ecstasy. The labs practices and technological investigations are dedicated to measure some patterns and electrical signals looking to provide for anthropological researches scientific material about how the body works and what kind of kinetic behavior and respective synaesthetic responses by the exchanges of electrical potential with the environment in the extremities of energies spent during rituals. The main focus is the body in ritual states rising to ecstasies such as the ceremonies that involve embodiments in deep levels of consciousness that come into ecstasy by their sensations of stimulation, and the sense of presence, albeit on condition of transcendence (the ecstasy, which we want to analyze, is significantly different from trance, related to unconscious states). Natural movements born of the internal excitations of the nerves and sensorial apparatus caused by the impression of the senses, often stored in memory beyond the possibilities of a motor body. We seek for those allowing such movements to conduct a survey on the concept of guided transphysiology, where the sensory movements may be stimulated and monitored in view of proposing altered affective presence. Laban’s paradigm postulate that human movements are always composed of the same elements, whether in art, at work, rituals than in everyday life. The actions allow – recognition in the form of rhythms and structures – the poiesis of a body.

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4. ENACTIONS AND EXPANDED SENSORIUM

The creative levels of performance with micro sensors for *coinaesthesia* – all the senses reaffirms the potential of affective aesthetics intertwining the body with the technological environment, by configuring perception as a laboratory phenomenon. Microcircuits of wearable physiological referenced in Maturana and Varela consider the interactions with the environment as sources of percepts, rather than mere representations and the body is involved in a neuropsychophysiological way, having mutual interactions with the whole environment.

Krueger emphasizes that “when made an experiment with synthetic way, we do not have access to the phenomenon itself, but the output of the sensor.” The whole body, woven into the environment, causes movement, gestures, voice, heat or other signal to be sent by perceived inputs and outputs from the interactive system. Biocybrid provides sensations in a relationship of mutual exchanges that take place during connections with emergent properties of the body and environment that is physiologically leased, resulting in reciprocal changes in behavior. Connectivity sum, therefore, the sensory physiology of the body and the qualities of the technological environment in which there is enacting which contributes to abandoning the original idea of separation between synthetic worlds and concrete worlds.

When interacting, the subject become more flow than subject and exchanged vital signals are processed building an environment unpredictable by “concrete actions, incarnated, embodied,” but adding traces from biological exchanged patterns. The coupled body is a data driven action, which means the perception in a state of autopoiesis. Physiological sensors provide sensations of liveness and presence in uncovering applications for wearable devices which interactions and bodily sensations are affecting our existence and how the environment affects our bios. It constitutes biograms as lived onto-topological events.

5. INTERACTIVE DATA VISUALIZATION - CINEMATIC FLOOR AND BIOCYBRID IMMERSIVE SYNAESTHESIA

Expansion of synaesthetic researches and biofeedback in immersive environments (CAVEs) using tracking and coupling body/environment/space, for navigation and responded gestures and the sense of proprioception are amplified in sensorial experiences for synaesthesia blurred to the sum of the physical world sensations in the cinematic floor of the CAVE. We propose a biocybrid CAVE with a cinematic floor which provides mixed sensations added to the enactive systems which provide embodiments when experiencing the floor and the effects of electronic circuits. The Kinetic Art of the 1960s and 1970s, using laws of Physics and Mechanics, is the source of such artistic development, and within the immersive cube the floor is equipped with electronic devices. In the history of art, the kinetic feed the artist imagination, we highlighted the Argentinian artist Julio le Parc who created the condition of unstable ground and body’s balance in the “Sol Instable”, an installation from 1964 that used plaques on the floor moves for each gait of the viewer while walking. The plaques provides episodes of vibration asking adjustments of the body to maintain itself in equilibrium for each new step. Participants, no more only viewers, acts in an interactive experience by the direct physical involvement while walking and has to pay attention on the qualities of the ground and adapt their way of going, walking and stopping and restarting. The constant condition to maintaining standing and the negotiation of the body with the environment given by the feedback of the tactile sense of foot on the floor remind us the considerations about proprioception as the integration of different senses highlighted by the enactive approach of sensorimotor skills given by Alain Berthoz.

The CAVE’s inventor, Carolina Cruz-Neira, proposed slipping effects with the floor, during her research at the University of Louisiana in the last years. We amplify the kinesthetic sensations using unbalances, shaking, impacts, varying rhythms etc., combined with a biofeedback technique based on different types of physiological signals. The background of this investigation was published in a chapter in.2

Another quality of the embodiments in the Cave is the biocybrid condition, taking Peter Anders’ concept of cybrid, enhanced by physiological signals by configuring an experience of mixed realities (bio+cyber+hybrid). The performatic immersion experience inside the CAVE allows replicate behaviors from physical spaces inside data space enhanced by physiological properties.

In this context, the biocybrid condition is expanded beyond art and entertainment, as it is applied to automotive engineering and biomedical engineering. In fact, the kinesthetic sensations will replicate the sensatio
of displacement in the interior of an automobile, as well as the sensations of vibration and vertical movements
typical of a vehicle, different speeds, collisions, etc. These various conditions will be created by the system
in terms of physical sensations and synthetic data provided by actuators, as well as by the biofeedback using
breathing, heat, heart beats and other signals collected by our physiological sensor circuits.

These resources may also be used in medicine and physiotherapy applications, as they provide, for instance,
different controllable movement conditions for a human body recovering from trauma. They may also be used
to simulate specific daily conditions, for the therapy of persons trying to overcome fears and phobias, to provide
a better understanding of human movements when subject to different types of movements, to evaluate people's
reactions under unknown constraints or on a new type of environment, etc.

5.1 System for the acquisition of the physiological signals

In the enactive system proposed in this paper, the necessary condition for the type of immersion we considered
is the real-time acquisition of physiological signals. We need to observe how these signals respond to the stimuli
inside the CAVE, and at the same time make the stimuli change according to the observed physiological changes.
This type of biofeedback is also explored in several applications of the enactive systems, in areas ranging from
entertainment to physiotherapy, sports training and rehabilitation.

In order to acquire the physiological signals under the specified conditions, we implemented a series of
compact, independent and synchronized electronic modules, which are responsible for measuring, digitizing, pre-
processing, and transmitting the signals of interest to our system: (i) the galvanic skin responses (GSRs), known
to change in response to different levels of stress or surprise; (ii) the plantar pressures of the participants as they
move or stand inside the CAVE, (iii) the abdominal movements associated to normal breathing, and (iv) the
heart beats.

The developed circuits were designed in order to satisfy the following specifications, which are required for
normal, nonintrusive operation inside the CAVE, as well as for the interaction to the central computers producing
the stimuli:

1. Reduced dimensions, so the circuits can be used as wearable devices without interfering with the partici-
pants’ movements and spontaneity;
2. Wireless transmission to the central computer, so no cables are required for the biofeedback (again not to
limit the participants' movements and range);
3. Independence between the modules, so that different combinations of sensors can be tested and a loss of
one sensor doesn’t influence the others’ responses;
4. Synchronization of the acquired signals, to allow a proper association between the stimuli and each signal
and for the analysis of correlations between the different tested variables;
5. Storage of the acquired measurements, for later analyses and validation.

Regarding the plantar pressure and the abdominal movement acquisition systems, we used a set of force
sensitive sensors (FSRs) to measure changes in pressure. In the first case, the sensors were positioned inside
biocompatible latex insoles, specifically designed for this purpose, so the participants can walk normally as the
plantar pressure is measured. Figure 1 shows a latex insole with 5 FSRs, as well as the positioning of the
acquisition system on a participant’s leg.

To collect and pre-process the signals, we used the EZ430-F2013 development kit by Texas Instruments,
which is equipped with the MSP430 microprocessor and with a WiFi module for transmission. In all the proposed
modules, the measured signals are digitized using the 12-bit analog-to-digital converters inside the MSP430
microprocessors. We used a sampling rate of the order of 2 kHz in the acquisition modules; combined with the
transmission rates by the WiFi modules, this resulted in an effective sampling rate of around 40 Hz in the central
computer. This rate is sufficiently high, by the Nyquist criterium, for all the considered signals.

Figures 2 and 3 show, as examples, the circuit for the measurement of admonimal movements and the layouts
of the GSR and the abdominal movement systems, respectively. Note in Figure 2 also an example of acquired
movement signal, in response to normal breathing.
Figure 1: (a) The biocompatible latex insole, with 5 force sensitive sensors used to measure plantar pressures. (b) The positioning of the plantar pressure acquisition system on a participant’s leg.

Figure 2: (a) The circuit developed for the acquisition of abdominal movements associated to breathing. (b) An example of signal acquired using the developed circuit.

Figure 3: The board layouts of the (a) GSR and (b) abdominal movements measuring systems.
5.2 The cinematic floor

To enlarge the corporeal sensations offered inside the CAVE, a treadmill is used for the displacements in the floor which responses for the immersion in the data landscapes. We have adapted: (i) A single-phase induction motor, a power of 0.5 hp, (ii) a sliding belt and (iii) a pair of pulleys, to establish its sliding velocity.

By default, the treadmill provides the user a sense of displacement by sliding action caused by the spindle motor. However, it is interesting to include a sense of unbalance to generate uncomfor to the user. In this sense, four springs of different sizes were fixed in the structure of the treadmill. The process of adapting a treadmill to add four springs is showed in Figure 4. Thus, the users try to adapt their movements to compensate the oscillations of the treadmill as well as to reestablish equilibrium. Then two sensations can be experienced in the treadmill, with sensations of: such as (i) movement or displacement, and (ii) unbalance or oscillation. Thus, some episodes are performed and different scenarios emerges form the immersion with respective physiological rates. The physiological sensors measures the behavior of the user in the context and provides input to the simulation to adapt the image and situations according the sineaesthetic responses.

![Figure 4: Assembly phase of the treadmill: different sizes of springs.](image)

To stimulate the sensations described three types of tests can be performed: (i) static oscillating floor, (ii) dynamic oscillating conditions, and (iii) start and stop sliding. Regardless of the test, the springs act on the structure of the treadmill. Therefore, the treadmill always has an oscillatory motion. In test (i) the users move in the area of the belt without sliding it. Thus, he compensates the oscillations. In the test (ii), the treadmill slips at a speed of 2.5 km / h. Here, the user adapts his walking to oscillations of the treadmill to keep his balance. Finally, in phase (iii), the user is prepared for starting and stopping the sliding action. Figure 5 shows details of a test of the treadmill inside the CAVE.

![Figure 5: (a) User testing the oscillatory motion and (b), (c) detail of springs of different sizes.](image)

In future activities, a speed control motor could be installed. Thus, the user can experience sensations of motion through reference signals for speed: a trot, a slow walk, a run, and speed variations.

The original idealized infrastructure for unbalance movements consists of using a simulator based on an existing actuators on the market that have already been installed in their structure. Other vehicular simulators,
is available to the CAVE for another type of tests dedicated specially for automotive engineer such as: Spanish PRO SIMTECH company specializing in the development of vehicular simulators. The ideal to be used in the physiological experiment the model would SIMBASE FRAME with 4 actuators D-BOX model 4250-i. This device allows the insertion of any interior geometry it is desired to simulated. And the great advantage of this basis is that this system uses a set of actuators with more possibilities of sensations to the user and its interface with other systems of the simulator is controlled by the simulation software already developed and tested.

It would require only the installation of accessories on the base, such as seats, steering wheel, shift knob, a treadmill of exercise (without springs) or other element to this base with actuators becomes a set of multisensory test in conformity with the necessity end of each experiment. In this case, the specific set would be mounted on the actuator base.

Meanwhile, the initial case, is the sliding floor to the base set with more actuators mat is characterized as an experimental apparatus with the ability to simulate a person walking or running on any terrain, slope variation of horizontal lateral shake, unstable environment, ie, a great multitude of possible sensations, it always linked to visual sensations designed by CAVE.

Another immediate use for this device would be for the vehicle simulation with physiological data and the driver using the CAVE as interface. This is the object of a work of PhD students working in the LART.

### 5.3 The Cavern of Transe Restoration

The complete biocybrid CAVE consists of a set of input signals, such as the real-time acquisition of physiological signals and users walking behaviors inside it, which generate the outputs of this system. The outputs are the oscillations provided by the cinematic floor and the visualization projected on the CAVE's walls. The Cavern of Transe is a sensor activated, immersively CAVE projected, interactive art installation conceived by Diana Domingues in 2004. Domingues created The Cavern of Transe to explore an interactive ritual, related to Afro-Brazilian popular religions, provided by embedded technology systems that endow people with expanded power to act in a cybrid space, by coexisting in both physical and digital worlds. North Brazil’s Pedra de Ing’s projections show metamorphoses sprouting from pre-historical inscriptions. People interacting become metaphorically shamans who consider the stone as a “veil” between their world and the “spirits’ world”. In terms of immersive technology of virtual reality, multi-sensorial interfaces enabled interactions by the use of wireless tracker which bluetooth communicates with the system and allowed spatial and haptic navigation. People’s displacements and gestures generate a proprioceptive interaction: by focusing with a lantern the walls of the cavern, a flash of light manipulates the virtual objects. This effect comes from the wireless tracker that simulated the lantern, which allows to touch, to move and change the position and direction of virtual, modeled objects: thunders, butterflies, spiders, vases, crosses, worm, animals appear in the room. Referring to immersion and mobility/immobility, people wearing the glasses have stereoscopic visions as other people, and manipulating the haptic tracker with tiny gestures they control the virtual objects. Each lighted object by the lantern (with the tracker) can be moved back and forth in the environment, and can be rotated in all the angles when the hand triggers the trigger button.

Another immersive property was experienced by wearing shutter glasses for stereoscopic visions. The tracked objects: tigers, spiders, stars, mosquitoes, thunders, sworms, and other symbolic elements invaded the room and the sensation of trance was enhanced.

Using Afro-Brazilian musical instruments: such as flute, maracas, whistles, afuxes, rainstick, shakers and other ritualistic instruments sent to a hi-fi microphone hi-fi provoked the interactions with the system. The synthetic objects are moved according the sound ryhtms. Little movements of the hands that play the instruments, it means, making noises, or with the mouth making sounds with whistles, flutes or with other instrument, and also when blowing them, or singing, whistling, people could interact with the system in a kind of ritual.

In the 2013, Dr. Carla Rocha expert on digital restoration started the Cavern of Transe restoration which is described on the section below. The restuoration is necessary for the adaptation to the enactive affective system technologies. Our solution to restoration problem is based on software engineering maintenance process. More specific, we are interested in the maintenance of legacy systems, where the digital artwork conceptual and technological foundations are frozen in time. Using the components characterization proposed by Marchese
The first stage of our restoration process consisted in identifying all four components layers of *The Cavern of Trance*: Artistic Experience, Artistic Software, Support Software and Hardware layer. This stage is crucial to the process, once it is imperative to maintain the Artistic Experience and the Artistic Software as nearly as possible in an unchanging state. Any other layer could be replaced or updated in the system, with no impact to the Artistic Experience.

*The Cavern of Trance*’s documentation includes: videos walkthrough of the artwork installation, files of all computer graphic generated models displayed, source code of the artwork, a brief technical paper about the artwork, datasheets of the hardware originally used. Neither an installation guide nor assembly guide of the installation were found and such manuals were essential to understand the interface between software and hardware.

The technical paper explained the software implementation process, but it did not give the functional requirements or the system architecture. It only mentioned that it used a distributed computing, where each computer managed one of the four projectors and these computers were connected through cluster.

To elicit the artwork’s functional requirements we ran an executable software of the original installation on the original hardware. We also had conversations with the artwork creator, Diana Domingues, and some of her collaborators. The artwork’s functional requirement obtained in the process that identified its capacities and characteristics are:

- The artwork would support four projectors;
- All four projections must be synchronized;
- The artwork’s sensors would capture user position within the CAVE reference system;
- The artwork’s sensors would capture the sounds emitted by the user;
- Sensors events would be communicated to the *The Cavern of Trance* program;
- The *Cavern of Trance* program would change the content of the displays and alter sounds.

Each projector displays on the CAVE’s wall Computer Graphics images/videos of a cavern and ritual objects, infusing its space with sounds complementary to the images showed. The original *The Cavern of Trance* had user’s position in the CAVE, sounds produced by the user, and a Wii Remote Controller, as input signals to interactive data visualization. These sensors and the computers used to process these data compose the Hardware Layer of the artwork.

We employ principles and practices from reverse engineering to produce the formal identification and documentation of the *The Cavern of Trance*’s software system. The artwork software was analyzed and its component parts were identified, paying particular attention to functions in the source code that were hardware dependent. At the end of this process, we recover the system design of the artwork *The Cavern of Trance*, as showed in Figure 6. The artwork software system comprises of an interface component, an Art component and a network component. The artistic Software composed by the set of functions responsible for rendering, playing music, and handling events. These functions must not be altered during the process of restoration, due to its importance to the Artistic Experience. The Support Software is the set of functions that enable communication to sensors, access directly a hardware, as video cards. In the *The Cavern of Trance* software, both Interface and Network components have functions accessing some hardware.

The second step of restoration consists on the process of recovering the artwork. Instead of using four computers to display the artwork, we use only one PC with a NVIDIA GTX590 video card, with 3 DVI outputs. The redeployment of the artwork from the windows Vista operating system (Original artwork) to windows 7 caused major chances to the application software, once we had to update the imported dlls, libraries, pre-compiled codes. Next, it was removed from the source code every function from the Support Software, so the remaining code would be independent to any particular hardware. This stage took the largest time effort, due to the lack of documentation, different implementation strategies adopted during the creation of the artwork,
The final step of restoration is to evolve the artwork The Cavern of Trance into an enactive system by adding the real-time acquisition of physiological signals. The Use Case Diagram of the Cavern of Trance with these sensors is showed in Figure 7. The sensors that affect the visualization are:

- The plantar pressure sensors: Each pressure sensor (there are five for each foot) data generates an event in which a “walk sound” is played. The volume of the sound is proportional to the data read. For each pressure sensor, one sound frequency bandwidth is played louder than the other frequencies. It gives the sensation of walking inside a real cave;
- The heart beat sensors: the heart beat data generates a sound event similar to the plantar pressure, with different sounds played according to the average heart beat;
- The abdominal movements sensors: the respiration generates an event to zoom the objects displayed on the screen, where amplitude of the zoom depends on the depth of the respiration.

The implementation of these new functionalities profit the design of the original Source code (Figure 6). It means that we implemented a new Interface Component and a new Network Component, adapted to the new functionalities and new hardware and sensors.

Figure 8 illustrates the resulting interaction between a participant inside the CAVE and the generated images and sounds.

6. CONCLUSION

We provided scenarios where users inside the immersive space of CAVE have their physiological signals acquired by wireless sensors that send the affective exchanges with the system and the environment during the enactments. Expanding the tradition of kinetic art and immersive interactive installation as well the previous CAVEs, the cinematic floor combined with physiological sensors allow a more intertwined relation between body, simulation...
and physical space. Something that we call as affective aesthetic for immersive scenarios configures the biocybrid condition which enhance the VR and synthetic environments for the most compelling experiences.

The proposal in Bioart and affective aesthetics focused on the expanded sensorium and investigate immersive qualities regarding enactive systems which enhance proprioception and kinesthesia into synaesthesia. We add to the responses of synthetic environments inside the cave, the sensations of the embodiments as lived experiences in physical world. The physiological sensors, aesthetically speaking, can translate human actions in a biocybrid
condition and make possible to Virtual Reality Reengineering Reality.

REFERENCES


