THE ARCONTINUO: A PERFORMED-CENTERED ELECTRONIC MUSICAL INSTRUMENT

Claudio Bertin
Escuela de Ingeniería
Pontificia Universidad Católica de Chile

Gabriel de Ioannes, Alvaro Sylleros
Escuela de Diseño
Pontificia Universidad Católica de Chile

Rodrigo F. Cadiz, Patricio de la Cuadra
Centro de Investigación en Tecnologías de Audio
Instituto de Música
Pontificia Universidad Católica de Chile

ABSTRACT

The Arcontinuo is an electronic musical instrument designed from a perspective based in the study of their potential users and their interaction with existing musical interfaces. The study of this interaction yields information that could give place to better interfaces, which respond to natural gestures in musical situations, and at the same time incorporate the latest advances in digital technology. The article explains the methodology fundamentals both qualitatively and quantitatively, focusing on two key elements in the performer interaction with instruments: gestures and objects. The statistical analysis of the results leads to the proposition of several mockups, one of which is chosen and described in details including its hardware and software implementation.

1. INTRODUCTION

The design of electronic musical instruments has been a discipline that has received an enormous contribution of creativity, but lacks of commonly accepted methodologies, often resulting in idiosyncratic and isolated approaches, with products with limited continuity over time. Throughout this article a novel design methodology is described leading to the Arcontinuo, an electronic musical instrument based on design research concepts [5]. The methodology is centered in the user and his interaction with a musical interface.

The analysis on qualitative and quantitative aspects of this interaction could allow for a better design of interfaces that respond to natural gestures in musical situations. At the same time better interfaces could improve the performance from the point of view of the audience, the cognitive aspects in learning and skills development, the exploration of tonal and rhythmic possibilities.

Acoustic musical instruments throughout history, while influencing the generation and interaction with music, have settled into canonical forms, taking centuries, if not millennia, to evolve their balance between sound production, ergonomics, playability, potential for expression, and aesthetic design. In contrast, electronic instruments have been around for little more than a century, during which rapid, often exponential, advances in technology have continually opened new possibilities for sound synthesis and control, keeping the field in continual revolution and allowing only a few instruments to be mastered by a significant community of players [8].

The aim of our proposal is to achieve a design process that, coming from the inter-discipline, focuses in the quality of the interaction between people and the artificial world. This implies the development of a participative and inclusive procedure, that incorporates aspects of the users cognitive and narrative identity. In other words, it means to include methodically the user’s point of view more than the designer’s.

The article begins with a description of the proposed methodology followed by analysis of the results obtained from testing the methodology on a group of subjects, to finally conclude with the implementation of a possible instrument, the Arcontinuo.

2. DESIGN RESEARCH AND IDENTITY INTERACTION

Evidence coming from biology and cognitive psychology shows that perception of the world or modelling of the environment, and consequently the notions of reality and quality, occur in a space of interaction conformed by the intersection between organism and environment; a relational space boosted by the mutual modification, in a permanent evolving process, and guided by the imperative of extract meaning by the way of interaction and recursion [11].

Human beings operate selectively in a space of interac-
tion from a particular identity, and the objects to whom they direct their modifications, also emerge as identities to his perception. Thus, there are personal identities and objectual identities, potentially in interaction.

Post-rationalist psychology redefines identity as a set of features and states that make an entity identifiable, and at the same time evolve in a process supported in a particular history of interactions, thus constituting a particular narrative identity. Narrative identity, then, has two dimensions: on one side, identity as *sameness* (Latin *idem*); on the other, identity as *selfhood* (Latin *ipse*). Sameness refers to the set of features that compose the being and provide to the identity a relatively stable continuity of the sense of itself. Selfhood, besides, refers to the collection of states that arise in the contingency, and represent the becoming with its breaks and haphazard perturbations.

The problem, in design and in other art disciplines, is to assimilate with major relevance and possession the viewpoint that considers the interacting identities. The assimilation needs to insert this perspective in the heart of the project. It is difficult to continuously project only from the personal perspective or from the purely design reference, basically because the design project is today, more than before, requested for a strong contextual dependence, that determines into a great extent its meaning and practicality.

Following this objective, Sylleros proposes a methodology for an identity research, explained in the following steps and summarized in figure 1:

1. Specify which are the personal and objectual identities that converge in the project.
2. Capture the narrative features that compose the sameness of these identities. This means to categorize emotions, explications, necessities, expectations, convergences and divergences. In the case of objects, it is possible to talk about features that can be morphological, technological, historical, artistic, and environmental factors, among others.
3. Capture the states that compose the selfhood of the identities. An ethnographic approximation (supported by digital technology) is helpful here, based in a multidisciplinary approach, that can register the ipso facto in the most rich and unprejudiced way possible, giving account of the situation or experience in terms of emotions, movements, verbalizations and ideas in humans, and a register of functions, flows, uses, codes, dynamics and modifications in the objects.
4. Measure and seek patterns in the information captures in relation to the above, with its consequent visualization, facilitating the diagnosis of intensity and experiential rhythm and recurrences in the behaviour, between other considerations. These allow to support quantitatively the qualitative findings.
5. Synthesize the results in a diagnosis and conclusions, through the specification of the critical interactions, that indicate where, how and why appear breaks and discrepancies in the identity seam, thus getting a strategic insight of how does the meaning emerge.
6. Finally, apply all the previous stages iteratively during the project. Through diverse ways of modelling, sketching and prototyping, evaluate and contrast results with the project objectives, as much times as being necessary in order to assure the pertinence of the project.

![Figure 1. Steps of the methodology for an identity research. It is possible to move iteratively between them, beginning from any one.](image-url)

### 3. SAMENESS STUDY

#### 3.1. Procedure

The first activity carried out was a focus group, a qualitative study consisting of an axial and open conversation about personal interaction with musical instruments: it was “axial” because the themes were put on, and “open” because every participant was free to express himself. The participants in the focus group were 20 subjects, most of them trained musicians with expertise in the performance of either acoustic or electronic instruments. We also included performers without any formal training and non-musicians. The guide questions requested by the moderators were about...
6 main issues: execution or articulation of the sounds; pitch, rhythm and timbre; cognition; performance; electronic instruments; and, finally, instruments in general. The answers were recorded in a digital video camera for its subsequent analysis.

3.2. Analysis scheme

According to the second step of the methodology shown in figure 1, the analysis of the focus group was aimed at capturing the narrative features of the participants. With that in mind, each intervention or opinion along the six themes of conversation was disaggregated in the following elements:

- Emotions: the apparent emotion that triggers the opinion. These were extracted from a taxonomy of emotions defined by Plutchik [9], who mapped it in the three-dimensional circumflex model. “The cone’s vertical dimension represents intensity, and the circle represents degrees of similarity among the emotions. The eight sectors are designed to indicate that there are eight primary emotion dimensions defined by the theory, arranged as four pairs of opposites. In the exploded model the emotions in the blank spaces are the primary dyads-emotions that are mixtures of two of the primary emotions” [9].

- Explication: a short explanation of the central idea contained in the intervention.

- Necessity or expectation: from the narrative and emotions of each subject’s opinion, was extracted a necessity or expectative that the person seeks to satisfy when playing a musical instrument.

- Narrative: a literal and representative sentence that summarizes the speech or opinion.

- Concepts: a short set of key words that show what each opinion talks about. It allowed further to find relations in the opinions along the conversation, and to have an idea of the importance or weight of each concept, according to the frequency of a concept among different opinions.

4. SELFHOOD STUDY

4.1. Procedure

With the aim of situating the study near the selfhood of the user group, we designed an activity that faces them to a contingent musical experience. A suitable model consists in requesting them to gesture a collection of different kind of sounds. The sounds were designed to cover different musical situations, as regards variations of musical parameters and nature or perceptual origin of the sounds. They were grouped in eight categories responding to diverse musical criteria: discrete timbre changes, tempered discrete pitches, continuous timbre changes, no-tempered discrete pitches with continuous timbre changes, discrete timbre changes through filters, instruments articulations, a noisy crescendo, and a set of acoustic instruments only (trumpet, cello, violin, flute, etc.). The origin of the sounds was diverse as well, including both electronic (elaborated with additive synthesis, FM synthesis, filtered white noise, physical models, etc.) and pre-recorded sounds of acoustic instruments.

Each category of sounds became in a single mix of around one or one and half minute of duration, namely a “sound series”. Each sound series was played twice: first, for listening purposes, and second, for the users to gesture the sounds as if they were playing them with some imaginary object or instrument. They do this with the eyes covered, in order to not feel ashamed and to prevent imitation between them. Moreover, the subjects did not know what are the parameters changing in the sounds or the name of the categories. The gestures were recorded by several digital cameras, in order to register in detail the whole group. Finally, they were requested voluntarily to make some notes or drawings about the object they imagined to articulate the sounds. This procedure was carried out for each one of the eight sound series.

4.2. Analysis scheme

The analysis of the two sources of data (video and notes) was made from two perspectives: the gestures of the users and the objects they referred to. The main information source about the gestures were the videos, as every body movement can be clearly observed. Besides, the written material supplied valuable information about the objects that the users visualized, through descriptions or sketches, while the video merely showed details about the spatial disposition of the object and the type of interaction with it.

The first step in the analysis of gesture and objects was to create a categorizing scheme for both separately, with the aim of codifying the information for a latter statistical analysis. It is important now to clarify what we mean by gesture. As Jensenius notices, the multitude of gesture definitions used in the computer music literature often results in much confusion and discussion [3]. In this article, gesture means basically what Jensenius calls movement, the act of changing the physical position of a body part or an object. We therefore used a gesture codification scheme based in osteokinematic or physiologic motions [4], which are the basic joint movements of the human body, described in the way other science disciplines do it, such as anatomy or kinesiology. These motions occur between the bones in space, thus, are visible through simple observation. The scheme, shown in figure 2, alludes to the accepted notion of musical gesture as human movement and not a static posture [7].
and does not recognize the direction of the gesture, i.e., flexion and extension are considered together as an unique basic gesture, as same as abduction and adduction.

Since as in this experiment the musicians stayed in their position and kept both feet on the floor during their performance, then the hip was not considered in the scheme. Besides, although the mouth is not exactly a joint, and blow and lips motions are not osteokinematic movements, they were included due to their occurrence and importance as musical gestures. As the scheme of figure 4 contains basic gestures, every complex gesture could be codified or disaggregated as a combination of those.

Although the scheme of figure 2 allows to represent gestures that use different joint movements for left and right limbs, by setting the prefix L or R before the respective identifiers, it has the limitation that does not capture asymmetrical gestures, defined as equal joint movements occurring in both limbs at different instants.

![Figure 2](image-url)

**Figure 2.** Categorizing scheme for gestures, based in osteokinematic motions, which are the basic joint movements of the human body.

On the other hand, the objects were categorized using an analogous scheme, shown in figure 4 based in their shape and the types of interaction of the subject with it. The shape included a category that explains the geometry, borrowing names of basic volumes from descriptive geometry, and adding the names of existing instruments and objects that appeared explicitly in the subject’s descriptions. The second category to define a shape was its dynamics, namely, how the shape changes over time. Interactions, in turn, are basic gestures to control musical events with an object 6, that could be an electronic or acoustic musical instrument or a part of it.

The study of the interaction of performers with musical instruments, following the procedure described above, provided qualitative information from the sameness study, and quantitative information from the selfhood study.

**Figure 3.** Categorizing scheme for objects, based in their shape (geometry and dynamics) and the types of interaction of the subject with it.

5. DATA ANALYSIS

Information from the first activity, the focus group, is summarized in a diagram that includes all the concepts extracted from them, shown in figure 4. The concepts appear within each one of the six addressed topics; the words connected with arrows show the oppositions that occurred in the discussion, while the size of the word is related to its recurrence, i.e., the times that the concept appears along the conversation. Concepts mentioned in more than one topic are located in the center of the diagram, that is to say, the most transversal concepts in the focus group. They are, in decreasing order of recurrence: timbre, corporal, progress, gesture, innovation, pitch, difficulty and challenging.

Using the schemes for gesture and objects of figure 2 and figure 3 all data of video and notes was retrieved and codified in order to find the elements and combinations that were most recurrent in the data.

5.1. Gestures

The statistical analysis of the gesture data yielded a quantification of the use of each basic gesture or combination of them in a musical performance, conceiving a basic gesture as a specific joint movement of figure 2.

As one might expect, the upper limb gestures were the most recurrent in all sound categories, especially elbow flexion and extension, shoulder motions and fingers flexion and
extension, as shown in figure 5.

We studied up to nine simultaneous basic gestures, in other words, we combined and observed up to nine different joint movements in a musical situation as one complex gesture.

5.2. Objects

The analysis of objects returned quantitative information about the features of the objects, as musical instruments or control elements, visualized by the user group.

In relation to the geometry of the objects (J column of figure 3), the most recurrent shapes were plane surfaces, stringed forms, spheres and cylinders. It was observed that subjects were strongly influenced by the source of the chosen sounds, that explains the occurrence of some acoustic instruments such as violin, keyboard and guitar.

Concerning to interactions with the objects, the results exhibited less variability, as almost every type of interaction had a significant occurrence (except pedalling), with a slight prevalence of rubbing and press/release. About the dynamic of the objects, rigid objects were the most recurrent.

Combining shape with interaction, the main results were press/release over a plane surface and plucking a generic string instrument. Other recurrent interactions over a plane surface were turning (a knob, for example) and rubbing, indicating a trend to more conventional electronic interfaces.

5.3. Gesture and objects

Finally, we carried out a global analysis including gestures and objects, joining the categorizing schemes of figure 2 and figure 3 in a single scheme, obtaining a single data matrix. This analysis yielded information about which gestures were more suitable to which objects, and vice versa. The most recurrent associations between gestures and objects can be summarized as follows:

1. The most recurrent basic gestures of figure 5 with rigid objects in general.
2. Elbow and shoulder flexion and extension with plane surfaces.
3. Elbow flexion and extension with rubbing interaction.
4. Elbow flexion and extension plucking a string instrument.
5. Elbow or fingers flexion and extension pressing in a plane surface.
6. Elbow and fingers flexion and extension plucking a string instrument.
7. Shoulder and elbow flexion and extension rubbing over a plane surface.
8. Elbow and fingers flexion and extension pressing over a plane surface.

Other objects, such as sphere, were associated mainly to shoulder and elbow flexion and extension; cylinder to blow gestures, sometimes accompanied with shoulder and elbow flexion and extension, interacting through blowing or singing.

6. IMPLEMENTATION

The study of gestures and objects resulted in a large set of possible prototypes and interactions that respond to the narrative identity of the user group. An initial mock-up was proposed guided by the sameness study conclusions and availability of resources. It was inspired by the most recurrent combinations of gestures and objects adapting the plane surface into a curved board because of performance and ergonomic considerations, as shown in figure 6.

Figure 6. The Arcontinuo. Sensor technology and functional features must be aimed at capturing finger gestures in a curved board.

In terms of gesture interaction, a surface capable of measure three-dimensional data simultaneously from several fingers is required. This surface must provide each finger position in the vertical and horizontal axis, as well as their pressure over it. A touch-pad interface could provide a good solution to this problem, however, the curved profile of the instrument constitutes an important limitation for these kind of surfaces. Another interesting approach is the Continuum instrument [2]. The design of this instrument provide some directions on how to address this problem but it has an important limitation: its implementation does not allow the detection of simultaneous fingers along the rods axis, providing only one finger detection at a given horizontal location.

6.1. Hardware

Our suggested solution consists on a magnetic flexible surface (e.g. foam, rubber or polyurethane layers with embedded magnets) with a grid of Hall-effect sensors underneath, which are available in the local market at a modest price. The necessary circuitry is very simple, consisting only on supply voltages and a by-pass capacitor. The Hall-effect sensors operate as position sensors, providing a voltage output that is proportional to the distance of the magnet above them. Adequately short distances between the sensors in the grid could capture several measures for each pressed finger, including a center and adjacent measurements, allowing the detection of the exact position of the finger and its pressure value in a continuous way [2].

The chosen interface involves tens or hundreds of sensors. In order to handle them, we designed and implemented a multiplexing module stage previous to the analog-to-digital conversion and posterior digital processing stage, inspired by keyboard scanning circuits, as shown in figure 7. The system electrically arranges the Hall-effect sensors in a square matrix of order $N^2$, using one $N$-channel analog demultiplexer for turning on/off the sensors, and one analog $N$-channel multiplexer to read their output voltages. These two elements can be implemented using the same device, such as the 74HC4051 of 8 channels, allowing to read 64 A1302 sensors in a single analog output, at a notably lower cost and complexity.

The circuit requires two supply voltages (0 and 5 V) and six control digital signals, to provide a single analog output, making an Arduino board [1] suitable to drive and register the sensor measurements. This platform offers ideal features for these purposes, since it includes analog-to-digital conversion (ADC), and provides easy-to-use communication tools with a variety of synthesis software, through USB connection or Bluetooth, thus allowing for a wireless operation as well. It is possible to identify the measurement of each sensor because of the six control bits, D0 to D5, which are set by the Arduino software. Moreover, the characteristics of the multiplexer/demultiplexer and the fast power-on time of the sensors allows for the maximum switching and measurement speed allowed by the Arduino ADC, namely 10 kHz for the whole system. In order to insure the supply current of the Hall-effect sensors (10 mA) and compensate the voltage fall of the demultiplexer, a switching NPN transistor is located in each channel, connecting the sensors to ground in order to complete their dual-supply operation, as
they are always connected to 5 V. Finally, a low-pass RC filter is placed at each input of the multiplexer for high frequency noise reduction, while the low frequency noise (such as the 50 Hz of the electrical grid) is attenuated with a bypass capacitor between the supply voltages. The Arccontinuo in its current incarnation utilizes 288 Hall-effect sensors.

![Schematic diagram of the sensors grid and multiplexing module.](image)

**Figure 7.** Schematic diagram of the sensors grid and multiplexing module.

### 6.2. Software

The software implementation consisted on three modules:

- **Data reading:** this module sets the ten control bits to drive the operation of the multiplexer and demultiplexer, and scans all 288 sensors, reading the analog outputs of the circuit (Vout1 to Vout3) through an analog-to-digital conversion. These measurements are successively stored in a data matrix that computes the difference respect to the default output values.

- **Blob detection:** each data matrix is treated as an image to apply segmentation techniques, borrowed from digital image processing. A threshold technique is applied on the image to detect blobs, which are the regions where pixels or lines are connected. An ID is assigned to each different blob.

- **Parameter extraction:** calculates the meaningful parameters for each blob, such as its center of mass and pressure, and send them through the USB port or Ethernet. Thus x, y and z coordinates are obtained for each finger in a frame.

### 7. CONCLUSIONS

This article presents a design methodology based on user’s feedback and their interaction with musical interfaces, that proposes concrete schemes for studying gestures and objects in musical performance. We propose that a performer-centered approach could allow for the design of interfaces that capture most recurrent or important gestures used in musical practice.

From the sameness study, we observed an emphasis on timbre, as well as on the important role of gestures in musical performance. The cognitive aspects of performing musical instruments were also relevant, through the progress in their learning curves and the balance between difficulty and simplicity. Finally, portability was seen as a desirable feature of a musical instrument.

The selfhood study yielded findings on gestures and objects used in musical performance. Upper limb movements were the most recurrent, in particular elbow, shoulders and fingers flexion and extension. Plane surfaces and string instruments were the most mentioned items, followed by generic shapes such as spheres and cylinders, with a uniform use most interactions. We also notice a tendency to relate to conventional electronic interfaces, such as mixing consoles or touch-pads.

Finally, the proposed approach allowed us to design mock-ups and interfaces that capture most recurrent gestures from musically moved users with a systematic, repeatable and collaborative methodology.

### 8. ACKNOWLEDGEMENTS

This research was possible due to the support of an interdisciplinary academic grant of the Vicerrectoría Adjunta de Investigación y Doctorado (VRAID) of the Pontificia Universidad Católica de Chile, and a research grant from the World Bank, Programa Bicentenario de Ciencia y Tecnología, Conicyt, Government of Chile.

### 9. REFERENCES


