Strategies for mapping control in interactive audiovisual installations

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Abstract. This article focuses on techniques to increase expressivity and intuitiveness of an interactive process in the context of audiovisual installations based on motion capture devices. We propose a series of strategies for mapping and data parameterization obtained from the analysis of visitors' gestures. Information retrieved from the analysis of gestures is interpreted in terms of its meaningful characteristics using descriptors of gesture segmentation, physical-domain characterisitcs (distance, velocity, acceleration and angular relations) and Laban's effort analysis. Effort allows us to differentiate quality of gestural movements aiming to increase responsiveness of the system for the data acquired in real-time from visitor's movements, thereby intensifying the interactive experience. By using simple techniques derived from physical descritors we have efficient data control and optimized computer processing. These techniques are being implemented through a framework of MaxMSP abstractions that determine constraints to retrieve information from the data streaming provided by Motion Capture systems. We present the resources developed and ongoing improvements of this framework for mapping.

Keywords: Movement Analysis - Installation Art - Mapping - Sonification - Interactive Systems.

1 Introduction

The relation between gestural controls and sound production has been studied from an instrumental approach that explores the similarity of the relationship between corporal actions and acoustic results [1], [2], [3], [4]. This leads to a more intuitive experience for the audience, motivating their engagement with the artwork. During the development of two audiovisual interactive installations - named *Abstrações* and *Cerejeira* - we systematized a significant problem to our study: the search for solutions to increase the effectiveness of immersion and interaction between visitors and computer systems [5], [6], [7]. Strategies for mapping and sonification provide suitable solutions to design this process.

The hypothesis suggested here is that it is possible to control the dataflow using information about motion segmentation and expressivity. The intention is to use physical-domain descriptors to optimize mapping configurations in order to increase the responsiveness of the system. In this study we aim to establish efficient strategies for parameterization, mapping and application of data acquired from the analysis of gestural movements performed by visitors in the three-dimensional space of installations. The main objective is to define mapping control resources that allow us to match intuitiveness and expressivity to the interactive process. Intuitiveness can be considered both as a result of the consolidated knowledge about everyday experiences underlain by shared cognition modules [8] or as how natural a performed gesture couples with the audiovisual outcomes, meaning that "obvious physical gestures should have an significant audible effect"[9]. Expressivity can be considered as the qualities of the movements associated to high-level properties that indicates how the gestures were performed in terms of *valence* and *activity*, valuing their positive or negative qualities and the intensity of related affects [10], [11]. Terms that define these qualities are often represented by adjectives and metaphors that can be inferred from the characteristics of the performed gestures.

Concerning the artistic approach of this study, we tried to set procedures to best control motion capture data. It is possible to choose between two approaches for interpretation of spatial information during the creative process. The first takes the global space of coordinates as reference, thus displacement is the absolute position of the visitor in the overall space. The second model is inspired by the system developed by Rudolf Laban for the notation of dance movements [12]. Laban's concept of kinesphere considers an imaginary sphere representing the space reachable by a dancer during extensions of the body. Laban's theory takes the center of weight of the dancer as the origin for all represented movements, which we interpret here as the origin for the coordinate system. Initially, this model considers only one visitor at time and gestural data is acquired individually. In situations where it is intended the presence of several visitors at the same time, the combination of both global and kinesphere systems can be used to determine relations between them. The concept of effort in Laban Movement Analysis has been implemented by interpreting movement through descriptors associated to qualitative aspects of segmented gestures. Camurri [10], [13], [14] used these descriptors to identify dance gestures as one component of the musical composition. The approach of that research to this issue is an important base for our study, since it applies Laban's effort descriptors as a mean to find out emotional characteristics (sadness, anger, joy, among others) from gestures. In this study we also incorporate concepts developed by Maes [15]. The model proposed by Maes fragments Laban's kinesphere in to a matrix of small target areas (see section 3.2).

The problem presented earlier concerning [6] lead us to search for more efficient methods to develop a creative process. Laban can improve relations between conceptual goals and retrieved data during the creative process. It should be noted that we are not working with action-oriented human motion such as dance or athletics. The target audience in this context is visitors of art exhibitions, disregarding any skills. The installation should also include features that can be enjoyed by skilled people such as musicians accustomed to interfaces and sound reactions to gesture, dancers and actors with experience in gestural and dimensional control of space or video gamers accustomed to control simulations of objects in digital media.

Several applications use gestural data to control installations and musical performances [15], [16], [17]. Most of them are tools developed for specific applications. The most significant researches to this topic were developed by Dobrian [2] and Camurri [10]. Dobrian developed an extensive research that includes essential functions to describe physical properties, movement description and derivative data from spatial coordinates: velocity, acceleration, distance and several other extra resources like inertia control and a player for recorded motion data. Camurri implemented the above mentioned solutions to extract expressivity from movements in performances, including dance and music. Camurri's solutions are based on associations with neural networks or knowledge databases, while in this study the main concern is the real-time motion data stream. The Digital Orchestra Toolbox [18] complements these resources with specialized spatial descriptors like jabbing detection or spring-mass models. In our study we start from these referenced tools to build MaxMSP abstractions with additional features, or adapting them to better reach our goals. The objective is to provide applications for gesture segmentation and also strategies for interpretation of these data, with the aim of using these expressive descriptors in mapping control. Included in this scope are the definition of different response curves and the creation of strategies for the distribution of spatial information based on parameters derived from raw data. These parameters are integrated with the Libmapper software [18] and the data flow is represented in Fig. 1. This enables dynamic and intuitive associations to manage structures that have motion data as input and audiovisual parameters as output.

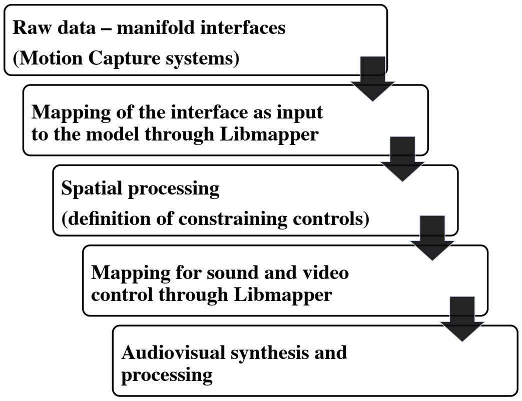


Fig. 1. Flow diagram of the overall proposed model.

The choice of a segmentation model relies on objectives and conditions that are defined by the context of its application. Gestural segmentation can be performed by either a top-down or a bottom-up approach [19], [20]. Bottom-up methods are suitable for situations that are limited by a high sample rate, when movements are unpredictable or when the existence of many primitives can compromise the performance. Considering the amount of data to be processed in complex audiovisual applications, as well as the fact that visitors are not restricted to a repertoire of predetermined gestures, we decided to implement bottom-up methods for segmentation. Bottom-up methods consists on making assesments over subsequent samples retrieved from the motion capture data stream. The descriptors presented in Section 3 use bottom-up methods to recognize gestural patterns such as changes in direction or the crossing of either distance, acceleration and velocity thresholds.

In the following sections we present the models being implemented for movement segmentation and introduce the potential of these resources to retrieve expressivity from gestures.

2 Implementation

In this study we try to combine both raw movement capture and gesture segmentation in order to allow composers to establish formalisms that relate input data to multimedia output. The raw movement data consists on trackeable points defined by markers that report us each cartesian coordinate in the three-dimensional space, represented by variables (x, y, z). These coordinates are the input data to the descriptors presented in Section 3. The kinetic model constitutes a set of markers defined by the composer, flexible to specific applications that does not requires a full body model and also flexible to include external objects as an extension of the kinetic model. Composers can define and work only with data relevant to represent segmentation and expressivity in a movement, optimizing implementation. The system described in this proposal is not restricted to a kinetic shape limited by a predefined skeleton, thus expanding the possibilities of its application. In this work we use the pattern of coordinate measures used in the Motion Capture system Vicon V460 to exemplify applications. These data are mapped to the input of the descriptors as vectors of three dimensions, where the effective area of capture in millimeters is in the range $-1600 <= x <= 1600$, $-1600 <= y <= 1600$ and $0 <= z <= 2300$. The total area of capture is in the following range, which is subject to occlusion in the extreme values because the field of view of the cameras $-2000 <= x <= 2000$, $-2000 <= y <= 2000$ and $0 <= z <= 2500$.

Concerning the secondary objective of developing a set of tools for gestural analysis compatible with several motion capture devices, the model was implemented based on the concepts of reference and changing coordinates. This concept allows composers to determine direct relations between selected trackable markers. The concept of changing coordinate denotes the marker that will have its movement tracked, from which displacements will be retrieved by descriptors. The concept of reference coordinate denotes the origin considered by these descriptors. The main difference remains on the chosen approach between two possible coordinate systems: a) a case where the origin of raw data $(0, 0, 0)$ retrieved from motion capture devices is also used as origin to assessments. In this case data will result from the absolute position of the changing coordinate in the trackeable space; b) a case where the origin of the calculations relates to another marker or point of reference, which is considered as the origin for our model inspired in Laban's kinesphere. In this case data will result from the relation between the position of both changing and reference coordinate. It should be highlighted that descriptors of angular relations need one more marker to be tracked, in order to retrieve the rotation of the kinesphere in azimuth and elevation measures.

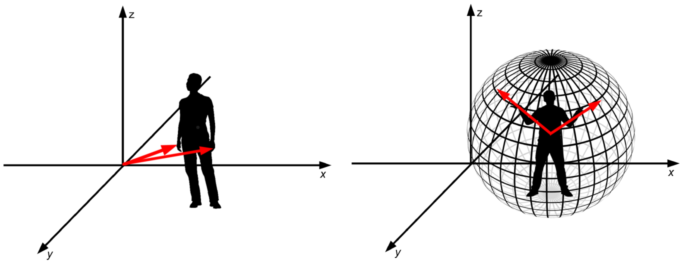
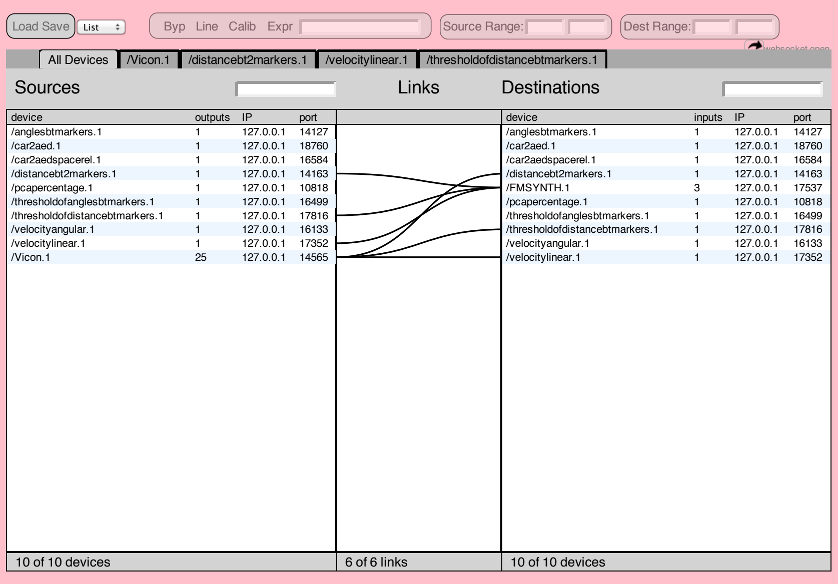


Fig. 2. Two possible origins for reference coordinate, tracking both hands. Left image takes raw origin as reference. Right takes kinesphere as reference.

The disadvantage of this kinesphere model is that the reference coordinate should consider all possible displacements between itself and the changing coordinate. This is because movement of the reference coordinate will interfere with the resulting data.

3 Streaming evaluation

The description of data processing in the proposed model is presented in Fig. 1. Motion capture for audiovisual synthesis and processing creates a complex network of data to be computed that can be affected by delays and jitter. For this reason, we avoided comparisons with databases, preferring to work directly with the motion data stream for gestural segmentation. Based on this approach we developed strategies to infer qualitative characteristics from movement. The dataflow is connected through Libmapper linking the input device to the modules for streaming data analysis. These modules currently being developed are processed inside MaxMSP. They can adjust mapping connections and data control based on an analogy to curves of response. Processed data controls modules of synthesis. These connections are presented in Fig. 3, which illustrates raw movement data arriving from Vicon; coordinates of the markers connect to descriptors of physical properties and segmentation modules; the output of these descriptors connect to synthesis and audio processing modules.



Sources

device	outputs	IP	port
/anglesbtmarkers.1	1	127.0.0.1	14127
/car2aed.1	1	127.0.0.1	18760
/car2aedspacerel.1	1	127.0.0.1	16584
/distancebt2markers.1	1	127.0.0.1	14163
/pcapercentage.1	1	127.0.0.1	10818
/thresholdofanglesbtmarkers.1	1	127.0.0.1	16499
/thresholdofdistancebtmarkers.1	1	127.0.0.1	17816
/velocityangular.1	1	127.0.0.1	16133
/velocitylinear.1	1	127.0.0.1	17352
/Vicon.1	25	127.0.0.1	14565

10 of 10 devices

6 of 6 links

Destinations

device	inputs	IP	port
/anglesbtmarkers.1	1	127.0.0.1	14127
/car2aed.1	1	127.0.0.1	18760
/car2aedspacerel.1	1	127.0.0.1	16584
/distancebt2markers.1	1	127.0.0.1	14163
/FMSYNTH.1	3	127.0.0.1	17537
/pcapercentage.1	1	127.0.0.1	10818
/thresholdofanglesbtmarkers.1	1	127.0.0.1	16499
/thresholdofdistancebtmarkers.1	1	127.0.0.1	17816
/velocityangular.1	1	127.0.0.1	16133
/velocitylinear.1	1	127.0.0.1	17352

10 of 10 devices

Fig. 3. Webmapper (graphical interface for Libmapper): Vicon output connected to physical descriptors, physical descriptors to synthesis module.

3.1 Basics: velocity, acceleration, distance and effort

In this study we propose two complementary solutions for the analysis of velocity and acceleration data. The first solution focuses on continuous control and immediate response to the movement taking place in relation to global or kinesphere origin. This model is useful for controlling parameters that evolve in time, such as synthesis of sustaining sounds or continuous sound processing. The assessments are reached by simple application of the Euclidian distance.

Let us take (x_0, y_0, z_0) as the kinesphere or global origin and (x_k, y_k, z_k) as the 3D position of changing coordinates over time in k steps. Eq. 1 defines the radius r_k between the origin and the changing coordinate as:

$$r_k = \sqrt{(x_k - x_0)^2 + (y_k - y_0)^2 + (z_k - z_0)^2} \tag{1}$$

Secondly, Eq. 2 defines the distance between two subsequent points in time as:

$$d_k = \sqrt{(x_k - x_{k-1})^2 + (y_k - y_{k-1})^2 + (z_k - z_{k-1})^2} \tag{2}$$

Given a sample period T over time, the instantaneous velocity v_k and acceleration a_k can be calculated as follows:

$$v_k = \frac{d_k}{T} \tag{3}$$

$$a_k = \frac{v_k}{T} \tag{4}$$

The following model is useful for controlling parameters after a gesture is completed, such as attack-resonance patterns. Given the instantaneous distance defined in Eq. 2 and velocity in Eq. 3, let us take a threshold l to define effort E_k by the following equation:

$$E_k = \begin{cases} \left(\frac{v_{max}}{t_{max} - t_k}\right) \times (d_{max} - d_k) \text{ if } v_k <= l \\ \left(\frac{l - v_{min}}{t_{min} - t_k}\right) \times (d_{min} - d_k) \text{ if } v_k > l \end{cases} \tag{5}$$

where:
v_{max} = maximum value of v_k since previous E_k
t_{max} = time in milliseconds when occured v_{max}
d_{max} = position in millimiters where occurred v_{max}
v_{min} = minimum value of v_k since previous E_k
t_{min} = time in milliseconds when occurred v_{min}
d_{min} = position in millimiters where occurred v_{min}

The implemented resources report only the first identified velocity value above or below threshold, respectively. Values should cross threshold to trigger a new output.

Effort values and their relations can be analyzed and interpreted to retrieve qualitative aspects that describe the amount of energy spent to accomplish the movement. The result of Eq. 5 can be interpreted as the intensity of the movement. High results for the first conditional of E_k can be associated to a performance with high effort, since they represent a fast deceleration with high values of maximal velocity and displacement in a reduced time interval; these results imply more force applied to slow down the movement. The second conditional can be interpreted as the effort intensity E_k for the starting movement. In this case low values of minimal velocity with high values of displacement in a reduced time interval imply fast acceleration.

Filters for time measurements and distance data are currently being implemented. A binary controller that indicates if the distance value is increasing or decreasing reports small changes in direction and respective time intervals, which can be useful to increase responsiveness of the audiovisual outputs either for movements realized in a small range. A simple example of how this resource can be used is to track the position of one hand in relation to the waist, which can control a sound frequency filter between high- or low-pass configurations if the hand is approaching or distancing in relation to the body. A standard deviation pattern interprets if the velocity is constant and how much it varies across time, identifying the flow aspect of Laban's effort; an also simple example of its application represents movement between bound or free, which can be interpreted as a movement hesitant or confident, respectively [12]. E.g. high values of standard deviation represents a bound movement characterized by inconstance of velocity, which can be associated to hesitant movements and associated to sound processings like detune or flanger. These two very simple examples presents how filters intends to optimize the range of values in relation to the space covered by visitors, thereby turning the control of the interactive environment of the installation effective either if the visitors make small or large movements. This solution increases the response of the system, especially when controlling sustained sounds, but should be implemented carefully in order to allow visitors to play with different dynamic ranges.

3.2 Kinesphere and angular relations

Angular relations between coordinates define parameters to sectional control that indicate the corresponding region of the kinesphere activated by movement into the spherical coordinate system. The model is ispired in an analogy with the division of a sphere into longitude and latitude. With this approach, we developed descriptors similar to the ones presented in the previous section, using data from azimuth, elevation and distance. These descriptors, together with an abstraction to segment the kinesphere into regions of detection, describe the section area of the sphere which the movement is driven to. Considering that each area in this model can act as a singular trigger for events or processings, the kinesphere model can also be used to determine target areas. Regarding situations where information about position inside the target area is needed, the system reports the displacement of the changing coordinate in azimuth and elevation.

Let us take r_k as the radius of the kinesphere defined in Eq. 1. The angular relations to $[x, y, z]$ coordinate planes are retrieved by $(\theta_k, \varphi_k, \psi_k)$:

$$C_k(\theta_k, \varphi_k, \psi_k) = \left(\arccos\left(\tfrac{x_k - x_0}{r_k}\right) \times g, \arccos\left(\tfrac{y_k - y_0}{r_k}\right) \times g, \arccos\left(\tfrac{z_k - z_0}{r_k}\right) \times g\right) \tag{6}$$

where:
$g = {}^{180}/_{\pi}$

The implemented model for segmentation of the kinesphere uses the spherical coordinate system, referred as azimuth (longitude), elevation (latitude) and distance (radius). Given m and s as the number of segments for the kinesphere, the model divides the angles in equally distributed steps as follows:

$$H_k^i = INT\left(\frac{\alpha_k \times m}{360}\right) \tag{7}$$

$$H_k^q = FRAC\left(\frac{\alpha_k \times m}{360}\right) \tag{8}$$

$$P_k^i = INT\left(\frac{\gamma_k \times s}{180}\right) \tag{9}$$

$$P_k^q = FRAC\left(\frac{\gamma_k \times s}{180}\right) \tag{10}$$

where:
H_k^i, P_k^i are integer part of the division respectively for azimuth and elevation
H_k^q, P_k^q are fractional part of the division respectively for azimuth and elevation
α_k = azimuth location of changing coordinate
m = number of segments for azimuth of the kinesphere
γ_k = elevation location of changing coordinate
s = number of segments for elevation of the kinesphere

The proposed model takes the two-dimensional integer quotient values to indicate the area of the kinesphere where the changing coordinate is pointing to in the instant k. The fractional part of the division indicates displacement of the changing coordinate inside the target area. This application of fractional part of division allows the control of transition processes between target areas, since it indicates movement direction and creates conditions to predict upcoming transitions.

3.3 Curvature and directionality: Principal Component Analysis

One of the major problems to segment directionality and curvature in the three-dimensional space lies on the correlation among data in the three axes that becomes more complex when we consider this descriptor applied to the visitor's kinesphere. This situation presents an independent coordinate system with a moving origin based on visitor's displacement that is dependent on the global coordinate system of the motion capture system. The proposed solution applies Principal Component Analysis (PCA) to create a rotational matrix that analyzes displacement from the rotational point that better describes the movement [20], [21]. The retrieved eigenvalues describe the movement's spatial distribution independently of the coordinate system (absolute or kinesphere), allowing interpretation of how its dimensionality is spread.

Let us take $\mathbf{I}$ as a matrix of dimension 3×3 formed by buffering the last 3 vectors sampled with the three-dimensional positions of changing coordinates, $\mathbf{U}$ as a real unitary matrix, $\mathbf{S}$ as a diagonal matrix with nonnegative real numbers on the diagonal and $\mathbf{V'}$ as the conjugate transpose of $\mathbf{V}$, a real unitary matrix:

$$\mathbf{I} = \mathbf{U} \times \mathbf{S} \times \mathbf{V'} \tag{11}$$

The values in the diagonal entries $\mathbf{S_{i,i}}$ of matrix $\mathbf{S}$ reports how movement is spread between dimensions. The implemented abstraction enables the segmentation of the curvature between linear and curved movements and is retrieved from the proportional distribution of the eigenvalues. For ease of use, the eigenvalues retrieved in the **S** diagonal matrix are normalized to percentage values at each sample and treated as a three-dimensional vector. This descriptor considers high values concentrated only in the first variable of the diagonal matrix vector as an indication of a unidimensional movement, such as linear gesture. Respectively, values distributed between two variables indicate a two-dimensional movement and values spread among the three variables indicate a three-dimensional movement. Qualitative evaluation of these data provide segmentation and association of gestures to specific targets; e.g. how effort and flow precede the reaching of a target area of the kinesphere.

4 Virtual Control to Entoa: example of application

In the first model to test the resources here proposed we implemented a redesign of the work *Entoa*, composed by the first author to the instrument Intonaspacio, developped by Rodrigues [22] at CITAR (UCP Porto) and IDMIL (McGill University). In this implementation we adapted the mapping of the instrument, intending to replace position sensors by processed data from our motion capture descriptors. Concerning our intention of to preserve a relation with the original spherical shape of the instrument during gestural control, we propose a model that builds a kinesphere around the left hand. The right hand performs free movements around the left hand, which will report us data of rotation in azimuth, elevation and distance among the hands and the left shoulder; these data replace the orientation reported by sensors of the instrument. The center of the kinesphere is associated to the middle finger and position of middle and thumb fingers provides information about rotation of the left hand. Thresholds of distance defined among markers placed in shoulder, left hand and right hand simulates the trigger of piezos of the instrument.

Figure 4 demontrates how the concept of kinesphere can be applied to kinetic models that does not require a specific body skeleton. The composer can determine any markers as reference coordinate, which are consequently considered as the center of weight of Laban's kinesphere. The results of our initial test confirmed the demand for filters to control input data. Noise in raw data required the use of mapping configurations tolerant to slight errors of positions for the markers.

5 Discussion

The proposed resources to interpret information from motion capture systems present themselves as a tool to support creative processes with a wide range of applications in gestural segmentation and expressiveness interpretation. They allow us to include expressivity as control parameters represented by effort from Laban Movement Analysis. Mapping allows to experiment strategies with different associations among the raw information data, the descriptors of physical

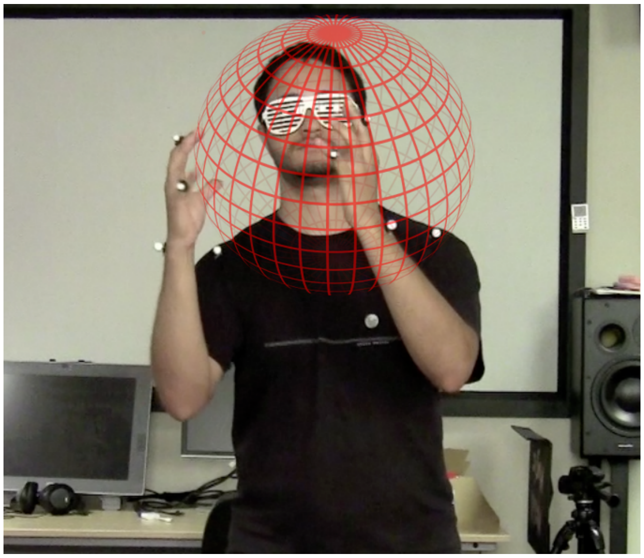


Fig. 4. Model of kinesphere applied to the left hand of the performer.

domain properties and the expressive control of devices for synthesis and processing of audio and video. Mapping also allows to optimize responses to the data informed by these descriptors, enabling a systematic approach to obtain better audiovisual results.

One of the main concerns consists of the implicit subjectivity when interpreting expressivity. In this paper some strategies to manage this problem are proposed. Still, there is not a simple or unique solution for this problem since the efficiency of its implementation deals with several challenges: the characteristics of the artistic project, the consistency of its conceptual associations and the commitment between the visitors and the artwork [4]. This study considers only the implementation level, presenting possibilities for expressive control of the interactive process. The potential of this research lies in the creation of analogies among the descriptors of physical properties, the additional characteristics to the segmentation processes and the audiovisual feedback to the visitors.

6 Future work

Future work consists of implementing several mapping strategies, which will include testing with more complex sound models that enable interaction and evolutive control in real-time. The intention is to analyze the feedback of the presented propositions. A graphical user interface (GUI) should be developed in order to optimize data control and visualization; this will provide resources to read and adapt data control in a fast and intuitive way.

Models are being adjusted using a marker-based motion capture system (Vicon 460). It is also intended to evaluate the compatibility of these models with other motion capture devices. Although main systems already are compatible with the cartesian coordinate system, the evaluation of the appropriateness of these resources should be done.

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