Towards the Concept of "Digital Dance and Music Instrument"

João Tragtenberg
Instituto SENAI de Inovação para TICs
Rua Frei Cassimiro, 88
Recife, Brazil
joao.tragtenberg@pe.senai.br

Filipe Calegario
Instituto SENAI de Inovação para TICs
Rua Frei Cassimiro, 88
Recife, Brazil
filipe.calegario@pe.senai.br

Giordano Cabral
CIn-UFPE
Av. Jornalista Anibal Fernandes, s/n
Recife, Brazil
grec@cin.ufpe.br

Geber Ramalho
CIn-UFPE
Av. Jornalista Anibal Fernandes, s/n
Recife, Brazil
glr@cin.ufpe.br

ABSTRACT

This paper discusses the creation of instruments in which music is intentionally generated by dance. We introduce the conceptual framework of Digital Dance and Music Instruments (DDMI). Several DDMI have already been created, but they have been developed isolatedly, and there is still a lack of common design guidelines. Knowledge about Digital Musical Instruments (DMIs) and Interactive Dance Systems (IDSs) can contribute to the design of DDMI, but the former brings few contributions to the body's expressiveness, and the latter brings few references to an instrumental relationship with music. Because of these different premises, the integration between both paradigms can be an arduous task for the designer of DDMI. The concept of DDMI can also be a bridge between DMIs and IDSs, serving as a *lingua franca* between both communities and facilitating the exchange of knowledge. Finally, we analyse two existing DDMI and describe two DDMI we created during this research. The conceptual framework has shown to be a promising analytical tool for the design of new dance and music instruments.

Author Keywords

digital musical instrument, interactive dance systems

CCS Concepts

•**Applied computing** → **Sound and music computing;** Performing arts; •**Human-centered computing** → *Interaction devices;*

1. INTRODUCTION

A significant advantage of digital technology for artistic expression is related to the unprecedented freedom of integration between diverse expressive modalities. With interfaces that allow the conversion of human movement into information, it is possible that a wide variety of gesture can control any sound, visuals, light or robotic media [5].

The field of artistic creation with digital technology is at least 56 years old [24] and presented considerable advances [17]. The area of Digital Musical Instruments (DMI) has been well delimited for a long time[26]. Unlike acoustic instruments, in which the equivalent energy of the gestural control is responsible for the sound production, the DMIs have open possibilities. The production of sound is independent of gesture control, being only connected by digital means. This freedom has allowed a much more full range of gestures to control sound production. For instance, there are DMI controlled by the positioning of several people in space [13], by eye movement [29], by muscle tension, [18] and by brain signals [12] to cite a few.

The area of Interactive Dance Systems (IDS) is another that puts digital technology in service to artistic expression. In academic literature, there has not been such a clear definition of the area, referred by different terms that vary in broadness like Interactive Dance/Music Systems [5], Interactive Music/Dance/Video Systems [8], or Multimodal Interactive System (MIS) [9]. Other terms were used, such as Interfaces for Dance Performances [22], Interfaces for Dancers [27], Sensor System for Interactive Dance [1] or Multisensory Integrated Expressive Environments [6]. Even though there is not a consensus on the terminology, we considered all these as parts of the area of IDS. These are digital systems used in interactive dance performances developed to enhance the expressive possibilities of dancers with sensors to capture their movements and produce sounds, visuals or movement through robotic actuators.

Several researchers have tackled the creation of digital instruments for symbiotic expression of music and dance. However, the initiatives rarely refer to one another, share conceptual frameworks, or join efforts in facing similar challenges of a broader area. To contribute in this direction, we propose a conceptual framework for Digital Instruments of Dance and Music (DDMI). The DDMI stand out from the DMI for the explicit concern about body expressiveness and present different characteristics from the majority of IDS given the instrumental relation with the musical production.

NIME'19, June 3-6, 2019, Federal University of Rio Grande do Sul, Porto Alegre, Brazil.

2. INSTRUMENTALITY

The concept of what makes an object a musical instrument has been brightly tackled by Sarah-Indriyati Hardjowirogo:

> "[...] instrumentality, or simply being a musical instrument must not be understood as a property an object as such has or has not. Rather, it seems to result from using something in a particular way which we think of as instrumental. Consequently, an object is not per se a musical instrument (ontological definition) but it becomes a musical instrument by using it as such (utilitarian definition) [...] the term must not be understood as denoting a property an object per se has or has not, but it is rather intended as a means of capturing the instrumental potential of a given artefact." [15]

The "degree of instrumentality" is a dynamic quality of an object, the result of cultural negotiation [31]. This degree depends on a series of factors that characterise the possibilities of human interaction with the artefact. The author lists several important criteria for the instrumental potential of an artefact: Sound Production, Intention; Purpose, Learnability; Virtuosity, Playability; Control; Immediacy; Agency; Interaction, Expressivity; Effort; Corporeality, "Immaterial Features"; Cultural Embeddedness and Audience Perception; Liveness.

3. ARTS INTEGRATION

Our main motivation to study the creation of DDMI is the demand of artists who are at the intersection between music and dance, interested in expressing themselves in both art forms at the same time.

The integration of the arts is an ancient quest in hegemonic Western history. The Florentine humanists of the seventeenth century introduced the concept of opera, referencing the theatrical traditions of ancient Greece which combined music, dance and poetry. Wagner, in the nineteenth century, brought the concept of unification of the arts (Gesamtkunstwerk) [23].

There are countless artistic traditions in which dance and music performance are inseparable. In the Brazilian traditions of *samba*, *forró*, *frevo*, *vanerão*, *maracatu*, *cavalo marinho*, dance and music play equally important roles. In several artistic contexts, the practice of each artist is of both languages at the same time. Some other examples are the various tap dance traditions (such as Fandango, Coco de Arcoverde, American tap dancing and Irish step dancing). The flamenco dance cannot be understood without the musical handclapping, foot stomps and castanets playing.

4. DANCE AND MUSIC

Some empirical studies have been conducted to prove the importance of body expression for musical perception. Several studies have analysed the expressive role of gestures that are not necessary to produce sounds [3, 11, 14]. Psychological studies have also shown how the visual cues may even have a stronger weight to the perception of musical performances than sound, even for an audience of trained musicians [20, 30, 32, 33]. These experiments have proved how music is not restricted to sounds but also includes visual and bodily aspects. They also reveal the importance of the musician's body expression for an expressive performance.

The seminal work of Mark Leman [21] "Embodied Music Cognition and Mediation Technologies" suggest a deep entanglement between the motor and auditory cognitive systems. These conclusions propose a new approach to playing music, to perceiving music[1] as well to designing musical instruments.

In the history of dance, the modern and contemporary movements marked a rupture with previous traditions, where dance was subordinated to musical compositions previously made. Martha Graham, one of the founders of modern dance, was a choreographer who marked this break by interfering in the process of musical composition, commissioning or suggesting changes in the music pieces from her choreography [23].

This detachment process was intensified after the interaction between the choreographer Merce Cunningham and the composer John Cage, where the choreography was conceived independently of the sound composition. Each had a different narrative, but they were presented together. The audience had the freedom to make their connections between dance and music and could switch attention between one and the other [23]. In Cage's words:

> "[...] in working with Merce, the first thing we did was to liberate the music from the necessity to go with the dance, and to free the dance from having to interpret the music." John Cage [19].

This rupture was essential to consolidate dance as a language independent of music, that is, without a hierarchical distinction. Being able to look at both equally opens possibilities to think about new possible relationships between them.

5. CONCEPTUAL FRAMEWORK FOR DDMI

The instrumental control of music by the dancer is not usually taken into account by the IDS researchers. On the other hand, musicians' body expressiveness is not frequently considered as a relevant asset for the DMI literature. It is a natural consequence from the musician's focus on sound production, and the dancer's primary concern in body movements. These bias, nevertheless, can generate much confusion to the DDMI designer, hindering its process of ideation and development of instruments for corporal and musical expression.

In this paper, we present a conceptual framework explicitly tailored to the DDMI designer taking into consideration aspects that are important for the DDMI architecture. This framework was based on elements of the DMI and IDS literature and also on research about IDS or DMI that we consider to be also DDMI.

Here is a list of some examples of DDMI that meet the main focus of this research:

- **Very Nervous System** - being one of the first IDS developed[2], it used cameras in a simple and expressive way. It is an important reference of interactive installations with an instrumental interaction [34].
- **Expressive Footwear** - it is a gestural interface in the form of a shoe with 12 sensors that are intended to capture the majority of gestural possibilities with the feet. [28]
- **Karlax**[3] - this instrument looks like a clarinet, but the absence of a nozzle and several other controls allow much greater freedom of movement as will be further analysed on section 5 [25].

[1] since we do not perceive music just through sound, it is not right to say we only "listen" to music
[2] A DDMI can also be an IDS
[3] http://www.karlax.com/

- **Prosthetic Instruments** - they are a series of physical artefacts used by dancers that can be attached to the body or freely manipulated as will be further analysed on section 5. [16]

This conceptual framework is intended to help in the creative process of a new DDMI. It can support the ideation phase by defining the instrument's core aspects.

This framework can also serve as a bridge between the areas of DMI and IDS facilitating the exchange of knowledge between these communities. Nevertheless, it is not in its scope to unify the IDS and DMI areas, but to create an intersection of both in a reduced scope to instruments for sound and body expression at the same time. Each of the parent areas should have broader interests regarding interfaces for dance alone or just for making music.

5.1 Conceptual Framework

For the development of DDMI, aspects related to musical production and body expression are essential. The paradigms of DMI and IDS can provide references, but the former presents few contributions to the corporal expressiveness, and the latter brings few inputs on an instrumental relation with the musical production. We, therefore, propose these conceptual framework taking elements that we considered relevant to the design of DDMI.

The conceptual framework of a paradigm is related to a model that is followed by its community to design new artefacts. It is a more general systematisation of different devices' architecture that helps to consolidate an area and to share grounding principles.

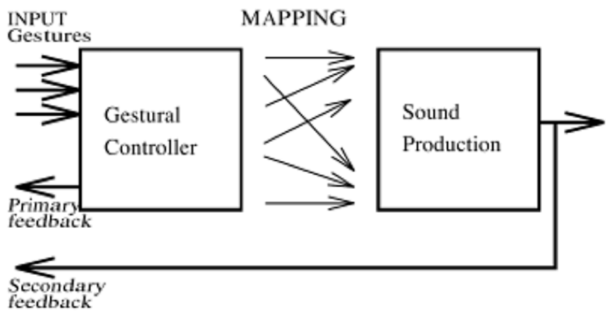

Figure 1: DMI's Conceptual Framework Diagram [26]

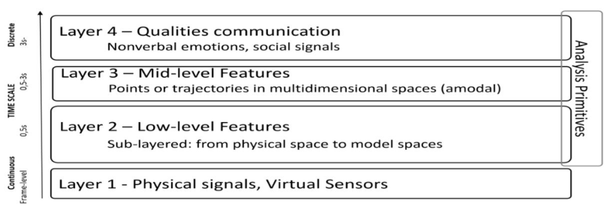

Figure 2: IDS's Conceptual Framework Diagram [10]

The seminal book "New Digital Musical Instruments: Control and Interaction Beyond the Keyboard" from 2006 proposed the diagram in Figure 1 [26]. It is a landmark in the area[4] and has influenced many DMI developers. A central concept is the technical independence of the controller and sound production units. The Mapping layer is maybe the most important concept, represented in a way to stimulate various mappings between the controller and the sound production unit. Another vital aspect of DMI's instrumentality is the instrument's feedback to the player for precise real-time control.

The best representation in the IDS literature is represented by a multi-layered conceptual framework of qualities of movement, best represented by the diagram in Figure 2 [10] first presented in 2001 [8] and mostly referenced in the 2003 paper[5] [7]. An important focus is on the processing of the sensor data generated by body movements into parameters with expressive content. It is a central topic of research in the Motion Computing community. Since the IDS main focus is on dance technology, it is natural to focus the framework on the body expressiveness.

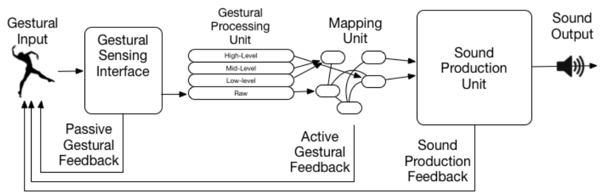

Figure 3: DDMI's Conceptual Framework Diagram

For DDMI, both frameworks are relevant but incomplete. We propose the diagram in Figure 3 to describe the conceptual framework of a DDMI. This kind of representation was inspired by both representations above, including the multi-layer gesture processing of the IDS and the feedback and mapping layers of the DMI.

It is important to point out that a fundamental gestural processing unit could be considered present in most DMI since there is signal processing on the sensor data to deliver relevant gestural control. The main difference in a DDMI is that this unit is to consider the signal conditioning to expressive gestures. In the same reasoning, and the DDMI conceptual framework could describe IDS, but the feedback and mapping layers are intended to give precise instrumental control over sound production.

The gestural sensing interface consists of sensors that perceive information from the body. The gestural processing unit is responsible for both the processing and interpretation of raw sensor data at different levels of abstraction. The mapping unit must process these qualities for the sound production unit in order to obtain interesting gesture-sound relationships. This last stage is composed of sound synthesisers or electromechanical actuators (loudspeakers or robotic instruments).

We chose to inherit the layers of feedback from the DMI since they are beneficial to build an instrumental relationship. Gestural feedback is responsible for communicating to the artist that the gesture was perceived by the instrument and can be given by passive interface elements (such as a click of a button or the elasticity of the instrument's structure) as well as by active elements (such as actuators luminous, mechanical or sound). The sound production feedback is responsible for returning information to the user about the sound produced by the instrument and consists mainly of the sound output of the instrument, but also can have analogous productions to this sound with projections, light indicators (such as VU bars) or mechanical (such as motors that vibrate at the frequency of sound).

[4] by April 2019 it had 487 citations on Google Scholar

[5] by April 2019 it had 441 citations on Google Scholar

Beyond what the diagram can describe, it is essential for DDMI to afford sound and body expressivity. For that, it is important for the instrument to allow precise control of the sonic parameters as well as not to restrict much of the body's movements. These affordances are to be taken into account by the DDMI designer in the creation. Sometimes it is necessary to trade-off one for another, but this choice should be conscious.

To illustrate better how this conceptual framework helps to understand existing DDMI and also in the development of new DDMI we will describe how it applies to 2 instruments cited above and two new instruments we have created.

5.2 DDMI examples

To better understand the DDMI conceptual framework, we describe two of the instruments mentioned above, the Karlax and the Prosthetic Instruments.

5.2.1 Karlax

Da Fact's Karlax is an excellent example of a DDMI. This instrument carries a direct instrumental inheritance [4] of a clarinet, a traditional instrument that allows great freedom of movement [30]. The absence of a mouthpiece and its other affordances allow a much higher body expressivity while playing it while its many buttons and pistons allow a precise instrumental sonic control.

The instrument is also equipped with accelerometers and gyroscopes that output to the user the raw data as well as the processed qualities of movement. It provides two-axis tilting and impulsivity (abrupt translation) for the six sides of translational movement having a multi-level gestural processing unit recognising expressive gestures.

Its sensors are divided into two parts whose ergonomics suggest that they are each touched by one hand. These parts are connected by an axis of rotation that perceives an expressive twisting gesture. There are also a set of four intensity-sensitive pistons, five continuous keys, a joystick and many buttons with tactile feedback that allow a virtuoso instrumental control of sound parameters. All data is sent to a wireless receiver that can be connected to a computer via MIDI or OSC protocols.

If a musician has only the intention to use it to control sound, it can be considered a DMI. It there is also the intention to dance while playing it, it is a good DDMI because it affords a lot of o freedom of movement by its lightness and size.

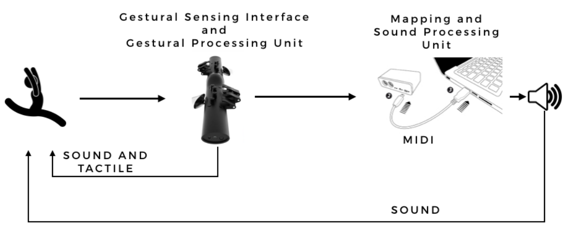

Figure 4: DaFact's Karlax

5.2.2 Prothetic Insturments

Other references for DDMI are the Prosthetic Instruments. They were described as a family of interactive dance instruments that could be perceived as new members of the body [16]. The instruments developed were the "Visor", the "Ribs" and the "Spine". The concept of an instrument as a prosthesis goes beyond merely placing sensors in the body. The material configuration of the prostheses mechanically interacts with the body, changing the possibilities and feedbacks from movement.

The DDMI "Spine" was equipped with two Motion Units with accelerometers, gyroscopes and magnetometers at the ends of the spine. The embedded gestural processing unit allowed an expressive read of its curvature and torsion. It was developed to minimise obstruction of the movement while maintaining some restrictions of some movements that were choreographically interesting. This is a good example of how freedom of movement is important for body expressivity but some limitations to it can also contribute to dance.

The "Visor" and the "Ribs" have, in addition to an accelerometer, capacitive sensors to detect touch and sliding finger gestures. The possibility of releasing the instruments and fixing them back on the body was conceived in a way they could be perceived either as part of the body of the performers or as objects. The tactile feedback and finger control allowed them to have a more instrumental relationship, affording more precise sound control. Some development criteria were adopted that guaranteed the instrumentality of the devices like low latency (around 5ms) and high-resolution data to allow subtlety of control. The libmapper library [22] was used as a mapping unit connecting the available gestural parameters to one or more of the custom synthesisers parameters programmed in Max/MSP.

This work was conducted by a team of digital instrument designers, dancers, musicians and sound designers. It is an excellent example of how an instrument can be made for dance and music at the same time. In this process, the musical intentions led to choreographies and movement definitions led to the musical composition through the DDMI design.

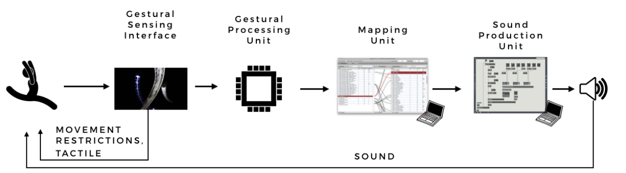

Figure 5: Prosthetic Instruments

5.3 New DDMI

We describe Giromin and TumTá, two DDMI developed by the authors, and how the DDMI conceptual framework aided their creative process.

5.3.1 Giromin

Giromin is a wireless wearable free-gestures DDMI. It was made to be worn around the torso and on the upper arm not to impose any movement restrictions. It was designed to amplify the gestures of continuous musical controls on synthesisers, usually done with knobs and sliders, still allowing a precise instrumental control with a direct analogical connection between what is seen and what is heard by the audience. It was motivated by research that suggested that the musical community in the Northeast of Brazil saw that it was important for electronic musicians gestures to be perceivable by the audience [2] and later used in the "Gira" performance.

Each wearable module was composed of an accelerometer, gyroscope and magnetometer, which could extract movement information without imposing physical restrictions. It used a sensor fusion algorithm to extract orientation data of each limb together with rotation speed and acceleration data. The arm's height, pointing direction and torsion and the torso's inclination and the whole body whirling movement showed to be very expressive. The gestural processing unit ran on firmware, sending the parameters wirelessly through OSC protocol to a computer to control hardware or software synthesisers. The range and mapping settings of input and output data could be done on a software interface.

The conceptual framework helped the design of this instrument in the choice of maximum movement freedom even though losing precision of sound control. Knowing these limitations, we searched for interesting mapping alternatives to continuous sound parameters that did not need such precise control and had perceptible relationships with the gestures like frequency and resonance of filters, LFOs frequencies, BPM rate of arpeggiators and direct amplitude control. The intuitive mappings with analogous sound and gesture, like the height of the arm to the frequency of a filter gave possibilities to intuitively control many parameters that would be impossible to control by one person through regular knob/slider interfaces.

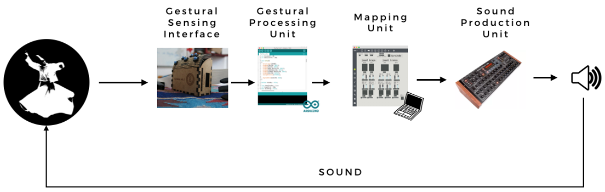

Figure 6: Giromin

5.3.2 *TumTá*

TumTá is a wearable instrument in the form of a pair of insoles to be placed inside the shoes. It detects heel foot stomps and triggers samples from them. It was designed to give new sonic possibilities to the bold foot stomping dance of Cavalo Marinho, a tradition from the Northeast of Brazil.

It was designed with a handmade pressure sensor from conductive foam and thread that was rugged enough to receive bold stomps. These insoles were connected through wires to a wireless transmitter belt, that did not constrain the dancer's movement. The gestural processing unit was responsible for recognizing the pressure variation instead of the raw pressure. That parameter afforded more impulsive foot gestures, which were closer to the dance that inspired the instrument design. Most keyboards have a similar gestural design, but the difference between this DDMI approach was to process the sensor signal based on the gestural expressiveness, instead of just the precise sound control.

There was software that converted the input signals into MIDI notes with velocities that depended on the foot stomps intensities, which were mapped in Ableton Live to a sampler. This DDMI was another wearable instrument that did not restrict physically any movement, but different than Giromin, it gave a more precise triggering control because of the pressure feedback it gave from the floor, allowing the player/dancer to make fast and precise rhythms that were both visually and musically expressive.

6. CONCLUSION

We proposed a DDMI conceptual framework with a set of arguments, references in literature and concepts to help the design of new instruments to make music and dance. It also aimed to argue in the DMI are in favour of body expressiveness and the IDS area on the benefits of musical instrumentality. This is an open proposal to be in constant evolution by the interested communities. This framework showed to have positive impacts on the development of two instruments (Giromin and TumTá), giving a more precise representation of what features a DDMI should have. We noticed there was a trade-off between movement restrictions set by the instrument and precision in musical control. In both cases we opted to give a higher weight for movement freedom, lowering the instrument's musical expressivity. This was not a wrong choice, but the most significant contribution of the DDMI framework was to make this a conscious choice.

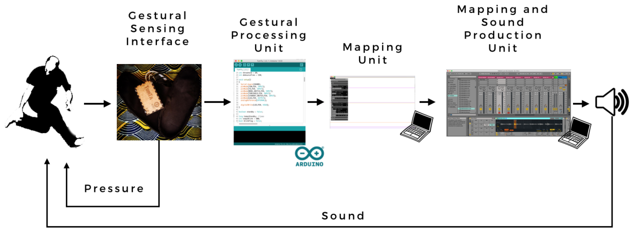

Figure 7: TumTá

7. FUTURE WORK

The DDMI conceptual framework has a lot to improve by validating it with a greater number of DDMI designers and users. A categorisation system for DDMI can also help the development stages of new instruments, helping to structure the knowledge from previous projects into common challenges and possibilities. An evaluation system could have a lot to contribute to the area as well. This way the framework could cover the whole design process of ideation, development and evaluation.

8. REFERENCES

[1] R. Aylward and J. A. Paradiso. Sensemble: A Wireless, Compact, Multi-User Sensor System for Interactive Dance. In *2016 NIME Proceedings*, pages 134–139, Paris, 2006.

[2] J. Barbosa, F. Calegario, J. Tragtenberg, G. Cabral, G. Ramalho, and M. M. Wanderley. Designing DMIs for Popular Music in the Brazilian Northeast : Lessons Learned. *Proceedings of the International Conference on New Interfaces for Musical Expression*, pages 277–280, 2015.

[3] M. Broughton and C. Stevens. Music, movement and marimba: an investigation of the role of movement and gesture in communicating musical expression to an audience. *Psychology of Music*, 37(2):137–153, 2009.

[4] F. Calegario. Probatio: Towards Different Levels of Mapping. Technical report, INRIA Lille, Lille, França, 2016.

[5] A. Camurri. Interactive Dance/Music Systems. *Computer Music Conference ICMC*, pages 45–252, 1995.

[6] A. Camurri, G. De Poli, A. Friberg, M. Leman, and G. Volpe. The MEGA Project: Analysis and Synthesis of Multisensory Expressive Gesture in Performing Art Applications. *Journal of New Music Research*, 34(1):5–21, mar 2005.

[7] A. Camurri, I. Lagerlöf, and G. Volpe. Recognizing

emotion from dance movement: Comparison of spectator recognition and automated techniques. *International Journal of Human Computer Studies*, 59(1-2):213–225, 2003.

[8] A. Camurri, G. D. Poli, M. Leman, and G. Volpe. A Multi-layered Conceptual Framework for Expressive Gesture Applications. *In Proceedings of MOSART: Workshop on Current Directions in Computer Music*, (1):29–34, 2001.

[9] A. Camurri and G. Volpe. Multimodal Analysis of Expressive Gesture in Music Performance. In S. J. and N. K., editors, *Musical Robots and Interactive Multimodal Systems. Springer Tracts in Advanced Robotics*, chapter 4, pages 47–66. Springer, Berlin, Heidelberg, 2011.

[10] A. Camurri, G. Volpe, S. Piana, M. Mancini, R. Niewiadomski, N. Ferrari, and C. Canepa. The Dancer in the Eye: Towards a Multi-Layered Computational Framework of Qualities in Movement. *Proceedings of the 3rd International Symposium on Movement and Computing*, pages 6:1–6:7, 2016.

[11] J. W. Davidson. Visual Perception of Performance Manner in the Movements of Solo Musicians. *Psychology of Music*, 21(2):103–113, 1993.

[12] J. Eaton, W. Jin, and E. Miranda. The Space Between Us. A Live Performance with Musical Score Generated via Emotional Levels Measured in EEG of One Performer and an Audience Member. *Proceedings of the International Conference on New Interfaces for Musical Expression*, pages 593–596, 2014.

[13] C. Frisson, S. Dupont, J. Leroy, A. Moinet, T. Ravet, X. Siebert, and T. Dutoit. LoopJam : turning the dance floor into a collaborative instrumental map. *NIME 2012 Proceedings of the International Conference on New Interfaces for Musical Expression*, pages 278–281, 2012.

[14] D. Glowinski, N. Baron, D. Grandjean, T. Ott, K. Shirole, K. Torres-Eliard, and M.-A. Rappaz. Analyzing expressive styles and functions of bodily movement in violinist performance. *Proceedings of the 2014 International Workshop on Movement and Computing - MOCO '14*, pages 154–155, 2014.

[15] S.-I. Hardjowirogo. Instrumentality. On the Construction of Instrumental Identity. In *Musical Instruments in the 21st Century Identities, Configurations, Practices*. Springer, Berlin, 2017.

[16] I. Hattwick, J. Malloch, and M. Wanderley. Forming Shapes to Bodies: Design for Manufacturing in the Prosthetic Instruments. *Proceedings of the International Conference on New Interfaces for Musical Expression*, (August 2016):443–448, 2014.

[17] A. R. Jensenius and M. J. e. Lyons. *A NIME Reader*, volume 3. Springer, 2017.

[18] B. Knapp and H. Lusted. A Bioelectrical Controller for Computer Music Applications. *Computer Music Journal*, 14(1):42–47, 1990.

[19] R. Kostelanetz. *Conversing with Cage*. Limelight, New York, 1988.

[20] C. Krahe, U. Hahn, and K. Whitney. Is seeing (musical) believing? The eye versus the ear in emotional responses to music. *Psychology of Music*, 10(8), oct 2013.

[21] M. Leman. *Embodied Music Cognition and Mediation Technology*. The MIT Press, Cambridge, Massachussetts; London England, 2008.

[22] J. Malloch. *A Framework and Tools for Mapping of Digital Musical Instruments*. PhD thesis, McGill University, 2013.

[23] P. H. Mason. Music, dance and the total art work: choreomusicology in theory and practice. *Research in Dance Education*, 13(1):5–24, 2012.

[24] M. V. Mathews. The Digital Computer as a Musical Instrument. *Science*, 142(3592):553–557, 1963.

[25] T. Mays and F. Faber. A Notation System for the Karlax Controller. In *2014 NIME Proceedings*, pages 553–556, London, United Kingdom, jun 2014. Goldsmiths, University of London.

[26] E. R. Miranda and M. M. Wanderley. *New Digital Musical Instruments: Control and Interaction Beyond the Keyboard*. A-R Editions, Middleton, 2006.

[27] J. Paradiso and E. Hu. Expressive footwear for computer-augmented dance performance. *Digest of Papers. First International Symposium on Wearable Computers*, (October):20–21, 1997.

[28] J. a. Paradiso, K. Hsiao, a. Y. Benbasat, and Z. Teegarden. Design and implementation of expressive footwear. *IBM Systems Journal*, 39(3.4):511–529, 2000.

[29] Z. Vamvakousis and R. Ramirez. The EyeHarp: A gaze-controlled digital musical instrument. *Frontiers in Psychology*, 7(JUN):1–14, 2016.

[30] B. W. Vines, C. L. Krumhansl, M. M. Wanderley, I. M. Dalca, and D. J. Levitin. Music to my eyes: Cross-modal interactions in the perception of emotions in musical performance. *Cognition*, 118(2):157–170, 2011.

[31] F. Visi. *Methods and Technologies for the Analysis and Interactive Use of Body Movements in Instrumental Music Performance*. PhD thesis, Plymouth University, 2017.

[32] J. K. Vuoskoski, M. R. Thompson, E. F. Clarke, and C. Spence. Crossmodal interactions in the perception of expressivity in musical performance. *Attention, Perception, & Psychophysics*, 76(2):591–604, 2014.

[33] A. Williamon and G. Waddell. Eye of the Beholder: Stage Entrance Behavior and Facial Expression Affect Continuous Quality Ratings in Music Performance. *Frontiers in Psychology*, 8(April):1–14, 2017.

[34] T. Winkler. Creating Interactive Dance with the Very Nervous System. *Proceedings of Connecticut College Symposium on Arts and Technology*, (April), 1997.