Representation of Samba dance gestures, using a multi-modal analysis approach

Luiz Naveda[*] [and] Marc Leman[*]
(*) IPEM – Dept. of Musicology, Ghent University, Belgium
E-mail: luiznaveda@gmail.com, Marc.Leman@UGent.be

Abstract

In this paper we propose an approach for the representation of dance gestures in Samba dance. This representation is based on a video analysis of body movements, carried out from the viewpoint of the musical meter. Our method provides the periods, a measure of energy and a visual representation of periodic movement in dance. The method is applied to a limited universe of Samba dances and music, which is used to illustrate the usefulness of the approach.

1. Introduction

In any human societies, dance and music appear as significant components of human expression [1, 2]. Samba represents the most recognizable Brazilian dance, music, social event and way of life. Our analysis focuses on the Samba-no-pé dance, a specific dance style, that is maybe the most recognizable dance style that populates the imaginary of Samba culture among Brazilians and also non-Brazilians [3].

1.1   Samba and multimodality

Samba performers, dancers, musicians, masters or listeners tend to understand Samba as a phenomenon in which music and dance are intrinsically related with each other. However, what is the actual knowledge about the structure of both domains?

Samba music structures involve a polymetric rhythmic texture, with large and strongly syncopated rhythmic formulas in the mid spectra. An ambiguous binary bar is supported by bass lines that accentuate the second beat and often damp first beat notes [4, 5]. Tatum lines in 1/4 beat onsets are concentrated in the high spectra and are subjected to syncopated accents and micro-time deviation profiles [6, 7].

Samba dances have been poorly described, such as in [8] and [9], who also take the musical context into account. Sodré [5] suggests that movement *pushes* the ambiguity of syncopation out of the music. Browning [9] refers to this effect as a musical capacity to provoke *hunger* of movement. All these descriptions acknowledge that body movement has a special place within Samba culture: body movement or dancing seems to be necessary to support the cultural form. It is a condition for music understanding. But how can these hypotheses about music and dance be tested?

The challenge to analyze highly multimodal contexts such as Samba is to develop tools that allow the penetration into the shared structure of music and dance. In this study we propose a method that looks for shared elements in dance and music at the metrical level.

In the following sections, we briefly describe the background of our study. In the second and third section, we summarize the analysis method and describe the representation of dance gestures. In the last sections, we demonstrate how our method leads to musically relevant analysis of dance gestures.

2. Analysis of multi-modal contexts

Samba dance was studied in detail by [10], [11] and [8], who provided us with different types of insightful qualitative analyses on Samba dance, based on subjective methods. Such methods can be complemented with new opportunities that describe gestures with the help of media technologies and computational tools. Computational approaches to dance analysis offer a promising new field for the exploration of dance because they provide access to levels of dance analysis that are difficult to examine by means of the traditional phenomenological methods.

Relevant work in this area includes that of Guedes [12] and Borchers [13] who developed real-time rhythmic analysis of dance respectively using video and sensors. Camurri [14] developed several video-based methods to extract and manipulate dance features in real-time, using the Eyesweb platform. Shiratori and colleagues [15] used musical rhythms to segment and classify dance motions. Jensenius [16]

proposed to use a technique called *motiongrams* to visualize structural aspects of dance movements caught on video. Matsumura et al. [17] studied skill acquisition of Samba musicians analyzing data from accelerometers that are attached to the body of dancers. However, the computational approaches that have been developed so far could profit from a multi-modal viewpoint to observed intrinsic relationships between dance gesture and music structures.

In this paper we propose a method that is based on a similar objective (third person) analysis of body movement but which considers Samba dance from the viewpoint of musical meter. Our multi-modal approach allows a proper representation of the basic spatial patterns that underlay the repetitive movement of different body parts along dances. To search for periodicities in the dance movements, we apply the Periodicity Transforms from Sethares & Staley [18], which we use in a proper heuristics that favours metrical structures. By analyzing the evolution of the shape of repetitive dance patterns we were able to grasp meaningful behavior of dancers engagement in meter. This allows us to make straightforward musically relevant descriptions that aim to clarify how dancers may perform their strategies of re-enactment.

3. Methodology for dance analysis

Our analysis method consists of three steps. The first step is to perform movement tracking of the dance in order to obtain the trajectory of the dance movements. In the second step, we perform a decomposition of periodic movements that are related to music periodicities (meter). In the third step, we use the results to analyze the evolution of localized dance movements from the viewpoint of the found metric periodicities.

3.1 Movement tracking and dataset

Two Brazilian professional dancers and teachers performed a total of 6 homogeneous and simple dance excerpts. 3 different Samba music stimuli were chosen from their own repertoire. The trajectories of 9 body points in the visual 2 dimensional plane of video were determined using manual movement tracking [see 19, 20]. It consists of marking the position (horizontal/vertical pixel position) of a desired visual element for each video frame. In this study, 9 points were identified and marked: nose, left shoulder, left rip, hands (left and right), knees (left and right) and feet (left and right). The procedure shown in Fig. 1 was performed using a specific patch in Eyesweb [14] platform.
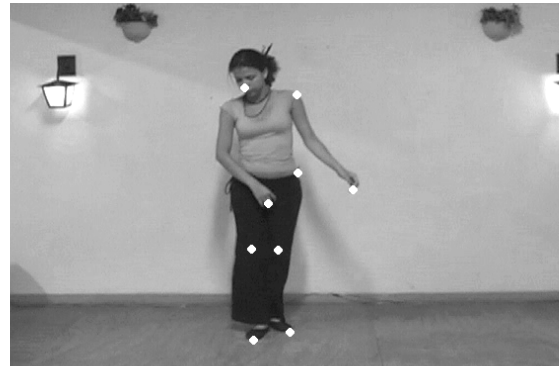

Fig. 1. Frame-by-frame manual tracking. Pixel positions are marked with the mouse using visual identification .

A set of 18 vectors (2 x 9 body part) was generated with the same temporal definition and spatial resolution of the DV video format (30 fps and 720 by 480 pixels).

3.2 Movement analysis

We use the Periodicity Transforms (PT) to find the most relevant dance patterns, relying on periodicity information from the metrical layers. The metrical layers, or the periods of the music meter grid, were here defined by multiples and divisions of detected beat period in the musical audio excerpts. It is expected that relevant periodic movements will synchronize with these periods. As such we use a multi-modal approach to dance analysis, based on musical meter information.

3.2.1 Metric Layers

Like most dance forms, Samba dance is rhythmically ordered to music, and Samba music is rhythmically grouped and organized by musical meter. Although Samba is rooted in non-western traditions, its evolution combined well-known elements of western music, such as isochronous beats, homophonic texture and a binary meter with elements of African music: rhythmic priority, polymetric lines, syncopation and rhythmic ambiguity [3, 21-24].

The beat markers for each musical excerpt used in the dances were extracted using manual inspection of beat tracking available in the software Beatroot [25]. To compute the bandwidth of the metric layer's periods, we used the mean beat period multiplied by the following metric rule: 0.25, 0.33, 0.5, 0.66, 1, 1.5, 2, 3, 4.

We incorporate knowledge from music into the heuristics to provide a better lens to the dance

phenomena. Our method uses meter and BPM information to select relevant information in the movement, mirroring the elements that dancers use to perform dances in synchronization with music structure.

3.2.2 Analysis of periodic patterns

The Periodicity Transforms (PT) basically searches for periodic events in the data. The PT was introduced by Sethares & Staley [18] and further applied in different fields of study such as rhythm analysis [26], analysis of brain waves [27], video and audio integration [28], data mining [29] and bioinformatics [30]. The core element of the algorithms is to decompose the signal in periodic sequences by projecting the given list of periods onto a "periodic subspace". The mathematics of the "projection" procedure is based in a modified form of the *Projection theorem* from Luenberger [31] and detailed in [18, p. 2956]. Sethares' implementations manipulate the projections of each periodicity, subtracting it from the signal, and then repeating it again using the next periodicity in the list over the residue. Implementations of PT provide an output of (i) the period of each repetition, (ii) the measure of energy (norm) extracted from the original signal by each periodicity, and (iii) the periodic basis (waveform) itself [for more information see 18].

Unlike other methods such as Fourier or Wavelet transforms, the PT finds their own bases, and these bases are non-orthogonal. It implies that different orders of projections and subtractions from the signal lead to different results. In other words, there is a preliminary list of periods, and its configuration of order and elements strongly influences the results. Like autocorrelation, PT offers a good definition in low frequencies (large periods), which proves to be more advantageous than Fourier methods. The latter are linear in frequency and lose definition in low frequencies. However, unlike autocorrelation, the PT approach allows the extraction of both the temporal aspect (duration of the beat) and the spatial aspect (the pattern between two beat points).

In our implementation of the PT concept, we use the dependency of PT on the configuration of the initial list of periods to develop a heuristics that mirrors the priorities of the dancer while moving along Samba music. Two simple priorities are applied in our heuristics: (1) that dancers would prefer movements that are repeated periodically around the musical meter and (2) that large movements would be more important that small ones.

Fig. 2 describes this process. The algorithm projects all periodicities until a given N number of samples (normally ½ of total samples of the signal) and filter the periods whose energy peak is above a threshold *th*. In the sequence, it selects only the periods whose peaks that are close to those of the music metric (they may reflect these layers and provide synchronized or counterpoint movements in relation to musical sound). Finally, the algorithm projects the periods of these powerful periodicities in a descendent order of energy, which aims to provide the "best" periods for metrical movements. These are the main points on which the so-called "Best-Route" algorithm relies. The diagram displayed in Fig. 2 subsume the main steps of the algorithm heuristics [for a more complete description of the method, see 32].
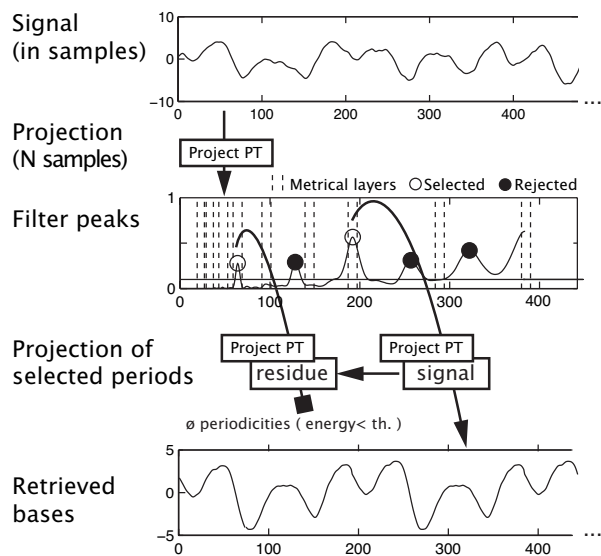
Best Route heuristics

Fig. 2. Diagram of the Best-Route heuristics.

If there are strong periodicities that are not synchronized with music meter such periodicities will not be selected. Ambiguous meter movements will be maintained depending on the domain knowledge imposed in the construction of the metrical grid. The lack of orthogonality allows irrelevant periodicities to interfere in the result. It also permits that the same movement can be seen from different perspectives, depending on the interpretation of the musical meter. Fig. 3 demonstrates the simulation of deviations applied to the metrical grid and the consequent elimination of non-metrical periodicities.
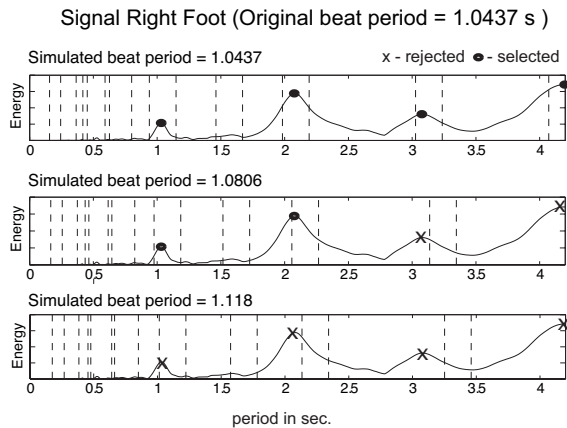
Signal Right Foot (Original beat period = 1.0437 s)

Fig. 3. Simulation of deviations in the metrical grid.

3.3 Spatial representations

By applying the *Best-Route* algorithm, we obtain the periods, energy measures (norm) and waveforms of the most powerful periodic patterns that match with the metrical grid.

However, periodicities from one dimension in time deliver incomplete information to our analyses because they do not re-integrate the two-dimensional vectors from a planar perspective of the video. An immediate solution for this problem would be to conjugate the periodicities found in the complementary dimension (in the last case, the vertical component). However, it is not guaranteed that the analysis of two complementary dimensions in a 2D movement plane shows strong periodicities in the same metrical layer. We solve this problem by "forcing" the PT projection of the missing relevant period onto the complementary dimension. Thus, if there is only one powerful periodicity for a given metric layer, we project its complementary dimension/period onto a periodic subspace without further manipulation of the list. By looking at all periods of the metric grid, and projecting all missing periods, we are able to output hypothetical 2D projections of periodic movements related to each metric layer. Relevant periodicities (powerfully evident and metrically relevant) are indicated by means of the Best-Route algorithm. Fig. 4 describes this process.

3.3.1 Decomposition of movement

The outcome of the Best-Route heuristics can provide 3 qualities of spatial representations:

- Bidimensionally evident (B), if the best periodicities are found in both vertical and horizontal dimensions at the same metrical level.
- Unidimensionally evident (U), if only one dimension (Uh-horizontal or Uv-vertical) was chosen as relevant by the algorithm.

- Evident periodicities (N), if both components are missing and the projection must be projected using the metrical level period in both vectors.
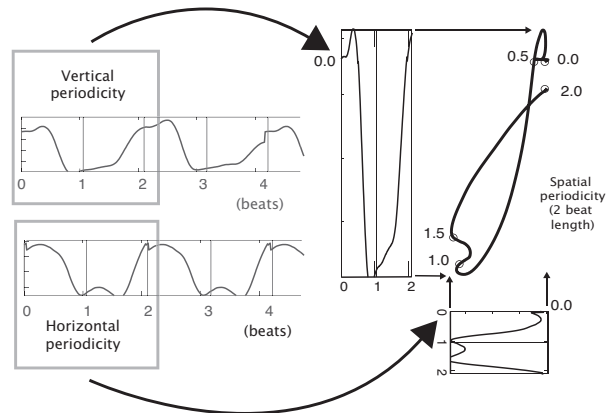

Fig. 4. Reintegration of movement in spatial descriptions.

As displayed in Fig. 5, the most relevant metrical levels show large visual magnitudes and are directly related with powerful periodicities found in one (B) or both dimensions (U) by the Best-route algorithm. This visualization also shows how the hypothesized movement may be evidenced by each metrical layer, although not all metric layers may be perceptually evident. Note that Bidimensionally evident (B) patterns are not necessarily the most evident ones, because secondary periodicities (weak) can be found at the same metrical layer.

This method provides not only a general basis of repetition that allows us to rebuild the trajectories in a periodic representation, but also a systematic connection with periods and relative energy measures of these movements. It surpasses frequency definitions of Fourier methods in low frequencies and shows insightful representations resulted from the projected periodicities (basis). The shape in the metrical level 2.00 seen in Fig. 5, for example, shows how the left hand movements are repeated on the video screen at every two beats during the dance. Each of these patterns can also be segmented into time steps, which provides us with detailed information about the evolution of the movement in each phase of the metric engagement. Fig. 5 shows one example segmented into half-beat steps.

By using this approach we can describe the dance form in terms of repetitive metric patterns. Spatial descriptions can be used to observe how repetition in dance movements shows the deployment of bodily engagement in Samba dance choreography, along with Samba music.
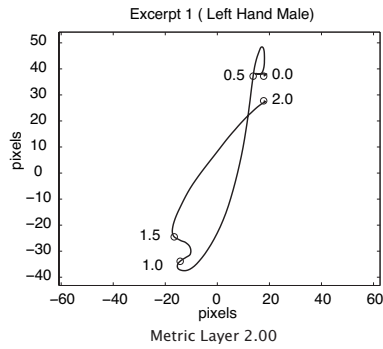
Fig. 5: Pattern of the left hand (male dancer, excerpt 1), in the metrical level of 2 beats (Bar). Marked points indicate 0.5 beat steps.

4. Results

In this study we show that repetition gestures in dance examples can be represented in a proper and meaningful way, using the above mentioned heuristics. For an easy recognition of indications, right and left sides will be referenced here as the viewpoint of the observer (inverted in relation to the dancer).

Fig. 6 shows descriptions grouped across metrical layers, plotted against one frame of its original video. This visualization provides insightful maps of gestures that visually cluster characteristics of movement patterns. Although the horizontal position is moved to separate each metrical layer (signalized in the bottom part) the reader can rely on the vertical position shifting the patterns horizontally to grasp the behavior of the body parts. Fig. 7 shows a gesture grid that compares the movement of the Right Hand in all metrical layers (columns) from all dancer excerpts (rows). Grouped gestures offer interesting visualization cues that make similarities and dissimilarities evident. Note that patterns from excerpts 1-3 (displayed in rows) show those of the male dancer, while excerpts 4-6 show those of the female dancer. Fig. 8 a-b shows 2 detailed descriptions, which demonstrate how gestures can be analyzed by its evolution in metric engagement (time).
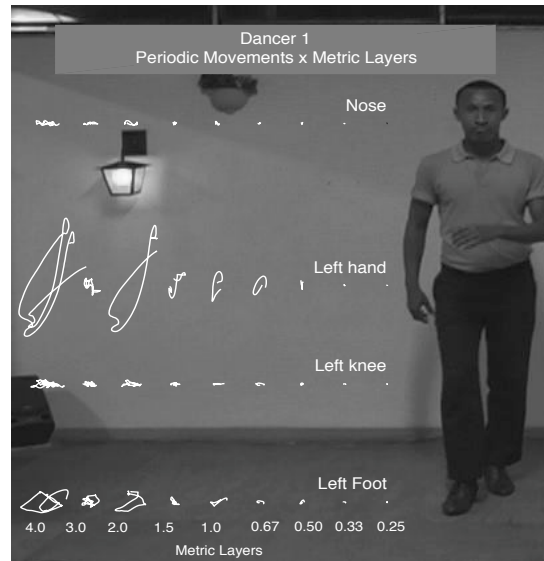

Fig. 6. Video frame of dancer, superimposed by groups of patterns by metrical layer.
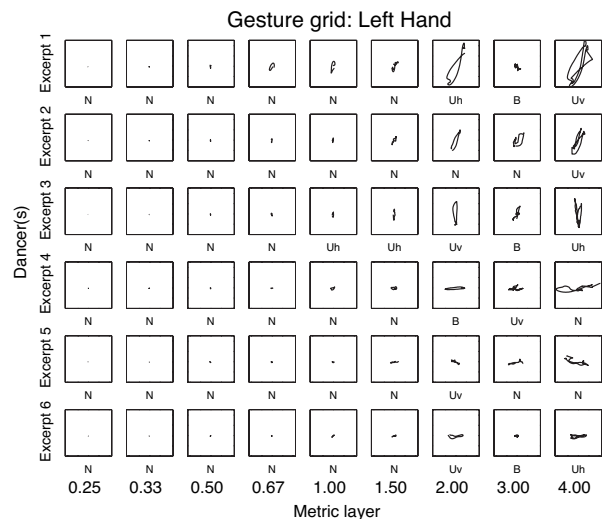

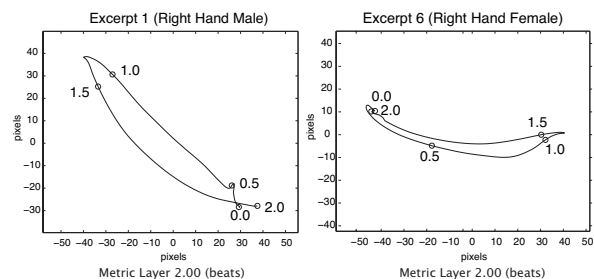Fig. 7. Grouped patterns representing left hand redundant patterns.

Fig. 8 a-b. Two examples of male and female left hand movement in the 2 beat metrical layer. Points marked indicate each annotated segment in 0.5 beat steps.

5. Discussion

It is questionable whether it is ecologically consistent to "encapsulate" the movement in arbitrary 2 axes (vertical and horizontal) while the dancer does not build artificial axes to perform her/his movement. However, the temporal marks such as beat and periodic lines are good musical indications that show links between movement and meter and musical time.

The grouped descriptions shown in Fig. 6, 7 and 8 provide interesting visualizations of how metric layers 2 and 4 (bar and double bar) are stressed in Samba dance engagement. Such characteristics were verified in all dances (1-6) by looking at the amplitude of the 7th and 9th patterns (2 and 4 beat metrical layers). Individual differences in these 6 dances interestingly emerge by comparing the patterns in rows. The grouped visualization in Fig. 7 shows that the male dancer (rows 1-3) tends to move his hand in vertical patterns, while the female dancer (rows 4-6) follows horizontally oriented gestures.

A more detailed analysis displayed in the Fig. 5 shows that thetic movement of the male dancer is concentrated on the extremity of these gestures. The evolution of his movement oscillates in fast changes before the beat marks (1.0 and 2.0). This suggests a strong gesture intention in the direction of beat indications, also verified in Fig. 8 a and b. Subtle movements mark 1.5 points, which could suggest a polymetric engagement, also denoted by emergence of patterns in the 3.00 beat layers in Fig. 7. Hands seem to stress beat points using displacement stops. Fig. 8 (a and b) shows an interesting comparison. Although the direction of gestures differ and the hands are in contra-phase (see 0.0 labels along patterns), both dancers change the direction between 1.0 and 1.5 beat points, which signalizes coherence of gesture forms between dancers. The female left-hand gestures seem to move more horizontally, in a pendulum-like form, while the male dancer tends to perform diagonal movements.

At the top of our observations, the comparison between video excerpts and representations suggests that our method provides relevant information about the dances. Successful sonifications of these patterns in Samba music sequences found by Naveda and Leman [32] also reinforces the extent of the method.

6. Conclusion

The representation, characterization and segmentation of repetition in movement by its relevant musically structures (meter) can provide a basis for a useful methodology in dance analysis, especially for dance forms. Our results show that the coupling between body and sound, culturally verified in the ecological domain, can be extended to the analytic approaches, generating relevant results. The extent of the method ranges from the detection of periods of repetition to the deployment of subtle characteristics of the movement into fractions of the musical beat. The method seems to confirm the link between Samba dance forms and musical meter, as proposed by several earlier musicological and anthropological studies.

7. Acknowledgements

References

[1] J. L. Hanna, R. D. Abrahams, N. R. Crumrine, R. Dirks, R. V. Gizycki, P. Heyer, A. Shapiro, Y. Ikegami, A. L. Kaeppler, and J. W. Kealiinohomoku, "Movements Toward Understanding Humans Through the Anthropological Study of Dance [and Comments and Reply]," *Current Anthropology,* vol. 20, pp. 313-339, 1979.

[2] A. Grau, "Sing a Dance. Dance a Song: The Relationship between Two Types of Formalised Movements and Music among the Tiwi of Melville and Bathurst Islands, North Australia," *Dance Research: The Journal of the Society for Dance Research,* vol. 1, pp. 32-44, 1983.

[3] M. E. Mariani, "African influences in Brazilian Dance," in *African Dance*, K. W. Asante, Ed. Asmara: Africa World Press, 1998, pp. 79-98.

[4] C. Sandroni, *Feitiço decente: transformações do samba no Rio de Janeiro, 1917-1933*: Jorge Zahar Editor: Editora UFRJ, 2001.

[5] M. Sodré, "Samba, O Dono do Corpo," *Rio de Janeiro: Codecri,* 1979.

[6] M. Wright and E. Berdahl, "Toward Machine Learning of Expressive Microtiming in Brazilian Drumming," in *International Computer Music Conference*, New Orleans, 2006.

[7] F. Gouyon, "Microtiming in "Samba de Roda"— Preliminary experiments with polyphonic audio," in *XII Simpósio da Sociedade Brasileira de Computação Musical* São Paulo, 2007.

[8] M. E. Mariani, "A Portrayal of the Brazilian Samba Dance with the Use of Lab Analysis as a Tool for Movement Analysis," University of Wisconsin, Madison, 1986.

[9] B. Browning, *Samba: Resistance in Motion*: Indiana University Press, 1995.

[10] M. A. C. Giffoni, *Danças folclóricas brasileiras e suas aplicações educativas*. São Paulo: Edições Melhoramentos, 1964.

[11] J. Chasteen, "The prehistory of Samba: Carnival Dancing in Rio de Janeiro, 1840-1917," *Journal of Latin American Studies,* vol. 28, pp. 29-47, Feb. 1996.

[12] C. Guedes, "Extracting Musically-Relevant Rhythmic Information from Dance Movement by Applying Pitch-Tracking Techniques to a Video Signal," in *Proceedings of the Sound and Music ComputingConference SMC06*, Marseille, France, 2006, pp. 25-33.

[13] U. Enke and J. Borchers, "Rhythmic Analysis of Dance Movements using Acceleration-Onset Times," in *Dept. of Computer Science* Aachen: RWTH Aachen University, 2006.

[14] A. Camurri, S. Hashimoto, M. Ricchetti, A. Ricci, K. Suzuki, R. Trocca, and G. Volpe, "EyesWeb: Toward Gesture and Affect Recognition in Interactive Dance and Music Systems," *Computer Music Journal,* vol. 24, pp. 57-69, 2000.

[15] T. Shiratori, A. Nakazawa, and K. Ikeuchi, "Detecting dance motion structure through music analysis," *Automatic Face and Gesture Recognition, 2004. Proceedings. Sixth IEEE International Conference on,* pp. 857-862, 2004.

[16] A. R. Jensenius, "Using motiongrams in the study of musical gestures," *In Proceedings of the 2006 International Computer Music Conference,* pp. 6-11, 2006.

[17] K. Matsumura, T. Yamamoto, and T. Fujinami, "Analysis of Samba Dance Using Wireless Accelerometer," *Nihon Kikai Gakkai Supotsu Kogaku Shinpojiumu, Shinpojiumu Hyuman, Dainamikusu Koen Ronbunshu,* vol. 2006, pp. 216-221, 2006.

[18] W. A. Sethares and T. W. Staley, "Periodicity transforms," *Signal Processing, IEEE Transactions on [see also Acoustics, Speech, and Signal Processing, IEEE Transactions on],* vol. 47, pp. 2953-2964, 1999.

[19] N. Rossini, "The Analysis of Gesture: Establishing a Set of Parameters," *Gesture-Based Communication in Human-Computer Interaction: 5th International Gesture Workshop, GW 2003: Genova, Italy, April 15-17, 2003: Selected Revised Papers,* 2004.

[20] M. Clayton, R. Sager, and U. Will, "In time with the music: The concept of entrainment and its significance for ethnomusicology," *ESEM Counterpoint,* vol. 1, pp. 1–82, 2004.

[21] C. Sandroni, "Dois sambas de 1930 ea constituição do gênero: Na Pavuna e Vou te abandonar," *Cadernos do Colóquio,* vol. 1, 2001.

[22] G. Kubik, "Analogies and Differences in African-American Musical Cultures across the Hemisphere: Interpretive Models and Research Strategies," *Black Music Research Journal,* vol. 18, pp. 203-227, 1998.

[23] P. Fryer, *Rhythms of Resistance: African Musical Heritage in Brazil*: Pluto, 2000.

[24] J. J. d. Carvalho, *Afro-Brazilian Music and Ritual [s]*: Duke-University of North Carolina Program in Latin American Studies, 2000.

[25] S. Dixon, "BeatRoot 0.5.6," 2007.

[26] W. A. Sethares and T. W. Staley, "Meter and Periodicity in Musical Performance," *Journal of New Music Research,* vol. 30, pp. 149-158, 2001.

[27] P. C. Lo and J. S. Leu, "Quantification of Pseudo-Periodicity of Alpha Rhythm in Meditation EEG," *Journal of Medical and Biological Engineering,* vol. 25, pp. 7-13, 2005.

[28] S. Ravulapalli and S. Sarkar, "Association of Sound to Motion in Video using Perceptual Organization," *Pattern Recognition, 2006. ICPR 2006. 18th International Conference on,* vol. 1, 2006.

[29] Y. Cai, R. Stumpf, T. Wynne, M. Tomlinson, D. S. H. Chung, X. Boutonnier, M. Ihmig, R. Franco, and N. Bauernfeind, "Visual transformation for interactive spatiotemporal data mining," *Knowledge and Information Systems,* vol. 13, pp. 119-142, 2007.

[30] A. K. Brodzik, "Quaternionic periodicity transform: an algebraic solution to the tandem repeat detection problem," *Bioinformatics,* vol. 23, p. 694, 2007.

[31] D. G. Luenberger, *Optimization by Vector Space Methods*: Wiley-Interscience, 1969.

[32] L. Naveda and M. Leman, "Sonification of Samba dance using periodic pattern analysis," in *Artech 2008* Porto: Portuguese Catholic University 2008.