Sonification of Samba dance using periodic pattern analysis

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***Abstract* — In this study we focus on the sonification of Samba dance, using a multi-modal analysis-by-synthesis approach. In the analysis we use periodic pattern analysis to decompose the Samba dance movements into basic movement gestures along the music's metric layers. In the synthesis we start from the basic movement gestures and extract peaks and valleys, which we use as basic material for the sonification. This leads to a matrix of repetitive dance gestures from which we select the proper cues that trigger samples of a Samba ensemble. The straightforward sonification procedure suggests that Samba rhythms may be mirrored in choreographic forms or vice-versa.**

***Index Terms* — Samba music, Periodic structures, metric levels, dance.**

I. Introduction

Samba represents the most recognizable Brazilian dance, music, social event and way of life. The culture of Samba in Brazil is not only a seasonal festivity of the well-known Carnival calendar. Instead, it spreads out in a variety of social or personal encounters, cultural manifestation, celebrations or introspective moments. Mariani [1] claims that the "*essential dynamics of the Brazilian society are being acted through the dance and this form of cultural representation*".

In this paper, we aim at understanding Samba as a phenomenon where music and dance are intrinsically related with each other, in ecological context. Our multi-modal analysis of Samba is based on a decomposition of dance in terms of underlying musical metric levels. This decomposition comprises both a discrete level, which we focus on the repetitive point in time (the metrical level analysis), and a continuous level, which we focus on the patterns that occur between the time points (the pattern level analysis). The method adopted is further inspired by an analysis-by-synthesis approach. In particular we justify the success of the multi-modal dance analysis by an explorative synthesis, or *sonification* process, which is based on mappings from the dance patterns into music. As a result of that, the latter then can be compared with the Samba music excerpts.

According to Kramer [2]:

> "*Sonification is the transformation of data relations into perceived relations in an acoustic signal for the purposes of facilitating communication or interpretation*." [2, p.3]

Therefore, our concept of sonification lies in a coupled artistic/scientific process that explores motion by looking for isomorphisms between music and dance gestures at the level of style. Sonification, in this case, facilitates the understanding of the relationships and similarities between coupled dance/music styles.

This paper has the following structure. In the first part (Section II) we discuss the background research in the fields of movement and music analysis. In the second part (Sections III to VII) we explain our methodology and discuss our analysis-by-synthesis method applied to a Samba dance excerpt. In the conclusion we suggest that Samba dance movements may encode or mirror Samba musical patterns.

II. Background

A. Samba as music and dance

The hypothesis on a close relationship between dance and music in Samba is sustained by different musicological perspectives and sources. From a historical perspective (sometimes controversial), the roots of Samba music are often linked to music forms as *Lundu* (first documented in 1780) and *Maxixe*, which followed an historical affiliation with dance forms with the same names. In the second half of the 19th century, a new choreography danced with *Lundu, Habanera* or *Tango* music styles resulted in the *Maxixe* dance [3]-[4], which emerges as a couple dance and a new musical form. The *Maxixe* announces the new Samba style that emerges in Rio de Janeiro's suburbs, in the beginning of 20th century. According to Sandroni [5], the modern Samba emerges in the 1930's, by the adaptation of music tempo to new "walking steps" of the Carnival parade.

Although descriptions of dance-music or body-sound negotiations are profuse, systematic descriptions of the motions related with dance forms are rare and, when available, very particular, with a lack of significance or clarity [6]. Fig. 1a shows dance footprints, usually presented in dance tutorials, whereas Fig. 1b shows a choreographical notation excerpt in Labanotation. For our purposes these descriptions can hardly be used because it is unclear how they relate to the music.

It is uncertain whether this lack of descriptions is a result of poor descriptive methodologies for movement analysis or whether it reflects the problematic application of a uni-modal approach to a highly multi-modal culture. Kubik [7], for example, found that the simplest way to detect common beat patterns along the percussion ensemble in the polymetric rhythms of the *Batuque of Benedito Caxias* (Brazil) was to look *"at the steps and general movement behavior of dancers"* [7, p. 138]. However, there are no descriptions of dancers' movements in this analysis. Sandroni [5] stressed the relevance of the walking steps in the Carnival parade that produced changes in the Samba form in the 1930's. However, in a contradictory way, he claims "(...) *it is not possible to say that a piece of music determines intrinsically the correspondent choreography, nor to deduce a musical style from a choreographical need*" [5,p. 137].

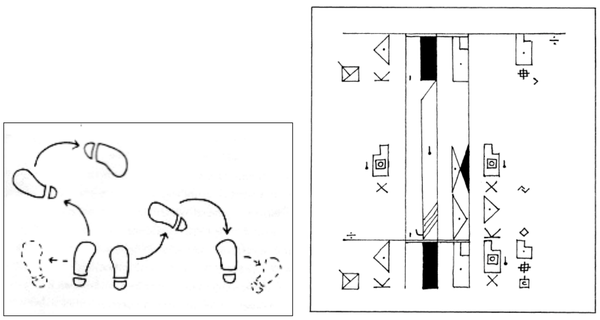

Fig. 1. (a) "Indecipherable maps of footprints" [6, p. xxii] often used to describe ballroom dances and (b) choreographical excerpt in Labanotation extracted from [8, p. 2].

Other studies stress the necessity to find novel methodologies that solve the interdependence between music and dance in multimodal phenomena. Blom and Kvifte [9] analyzed dance and music performances of *Gangar* music and suggested that the intrinsic metrical ambiguity could only be solved by the dancer's movements or by the traditional musicians playing together with dancers. Using examples of Norwegian Springar dance, Kvifte [10] criticizes the idea of imposing meter definitions using isochronous time marks. Analogous to Kubik [7] Kvifte claims that dance movements are central to define meter units. In African music contexts, which form the most important background of Samba culture, several studies provide a number of similar observations about the coupling of music and dance. Chernoff [11, p. 1101] claims "*when the* [African] *music relinquishes its relation to movement, it abandons its participatory potential*".

The necessity to consider music and dance as a whole phenomenon in Samba culture has been presented by Sodré [12] in late 70's, and more recently by Browning [6]. Both authors clearly remark on the effect of syncopated rhythms to produce movement reactions in the listeners, or what Browning [6, p. 9] defined as "*hunger*" for movement. Other authors, such as Fryer [4] and Carvalho [13], stress that the performatic unit in Samba culture is inherited from Afro-Brazilian rituals. Such religious traditions flourished within inter-textual contexts, in which the "*playing of instruments, dance movements, formalized costumes, kinetic displays, dramatization, etc, all these aesthetic expressions put together create an environment which passes the idea of continuity*" [13, p. 10].

B. Computer-based analysis of Samba

In a recent study using computer techniques in music analysis, Gouyon [14] analyses the micro-timings of 16th notes in Samba polyphonic audio examples, revealing systematic deviances in the 3rd and 4th onsets in each 4-group notes in the Tatum layer (see also [15] for a similar study). Wright and Berdahl [16] studied micro-timings of *pandeiro* rhythms in Samba music trying to describe the "swing" structures by means of machine learning. Former studies have also approached Samba music from the viewpoint of music information retrieval. Gouyon et al. [17] was able to reach 53% of performance in beat detection of Samba songs within a database of 1360 songs (various styles); Dixon et al. [18] developed a method to classify genres with up to 99% of recognition of Samba style, based on the characterization of rhythmic patterns and other features. These studies, however, define Samba as a quaternary form, whereas most musicologists would define Samba as a binary meter music form. After close inspection of the Samba music excerpts in these studies it becomes clear that that they were based on ballroom dance music (www.ballroomdancers.com), and not on genuine or original Samba music (see brief characterizations in sections II.A, II.C and VII.B). Moreover, although the musical context of swing or ballroom dances is commonly related with dance, none of the studies offered choreographic descriptions.

In short, our approach differs from the prior studies in dance and music information retrieval in that we are more concerned with the multi-modal nature of Samba, and in particular with the intrinsic relationship between music and dance. Therefore, we are focusing more on the mutual dependencies in timing aspects and on spatial aspects of dance in relation to music.

This idea comes from a corpus of research which stresses the fact that some of the core elements of musical expression, perception and performance are not only an externalized by the body, but strongly affected by how we mediate our musical thinking with our body [19]. In that sense, we could argue that a close interaction between music and body movement takes place in Samba through mutual influences between playing and dancing. We don't answer the question whether dance can have an impact on players. Instead, we focus on how music influences the dance and how the body mediates the understanding of that dance. This study explores the potential existence of a shared vocabulary between music and dance forms, through an analysis-by-synthesis approach. In this approach, the analysis focuses on how dance patterns reflect music, while the synthesis focuses on how dance patterns can be translated into music.

We use the Periodic Transforms (PT) algorithm by Sethares and Staley [20] to extract periodicities from dance movements. To find these periodicities, however, we look at the dance movements from the viewpoint of musical meter. In other words, we scan the dance patterns at timing levels that correspond with timing levels at which sonic repetitive patterns occur. The analysis strategy is applied and limited to the *Samba-no-Pé* dance, and the resulting periods are used to recreate Samba music forms. *Samba-no-pé* is a specific dance style, and maybe the most recognizable dance style that dominates the imaginary of Samba among Brazilians and also non-Brazilians.

III. Methodology for movement and sonification

The process to develop mapping strategies that translate movement trajectories in music structures can be divided into 3 challenges: (A) the extraction of relevant model of periodic patterns from movement, (B) the identification of the relevant musical and choreographical features to be mapped from this dataset and (C) a set of mapping rules to (re)create music textures.

A. Extraction of periodic patterns in dance movements

The first problem is related with techniques that analyze the movements of dancers. We use the Periodicity Transforms (PT) approach to develop an algorithm that finds the most relevant repetitive dance patterns. To find these dance patterns, we use information from musical meter, or more specifically the periods of each metrical layer. Therefore, we use a combined approach based on common periodicities in dance and music.

First of all, we will have a look at the concept behind the Periodicity Transform. This kind of transforms was first proposed by Sethares and Staley [20] and further applied in different fields of study such as rhythm analysis [21], analysis of brain waves [22], video and audio integration [23], data mining [24], bioinformatics [25]. The Periodicity Transforms has its origin in the work of the Dutch chemist and meteorologist Buys–Ballot (Buys–Ballot's table), who determined hidden periodicities in the signal. In other words, it searches for periodic events in the data. The core element of this process is to decompose the signal in periodic sequences by projecting the given list of periodicities onto a "periodic subspace". Sethares' implementations[1] manipulate this process by projecting each periodicity from a list of periods, subtracting the projection from the signal and repeating the procedure using the next periodicity over the residue. Implementations of PT provide an output of (i) the period of each repetition, (ii) the energy extracted from the original signal by each periodicity, and (iii) the periodic basis itself (waveform). The energy extracted from the original signal by the periodicity (transform/original signal ratio) is calculated as the induced norm (*Euclidean norm*) of the signal [see 20, p. 2954]. Unlike other methods such as Fourier or Wavelet transforms, where the basis of the transformations is defined *a priori*, the PT find their own basis, but this basis is non-orthogonal, and as a consequence the periodicities are not independent from other. This implies that different orders of projections for the list of periods in subsequent subtractions from the signal lead to different results. Fig. 2 shows the results of an implementation proposed by Sethares and Staley. Note that this approach allows the extraction of both the temporal aspect (duration of the beat) and the spatial aspect (the pattern between two beat points).

Sethares and Staley [20] proposed 4 types of algorithms, namely: Best-frequency, Best-Correlation, M-Best and Small-to-Large. These implementations basically differ in how to select and order the set of periods to be projected. However, as noted by Sethares and Staley [20], the key to develop useful algorithms based on PT lies in how to design an internal heuristics that reflects the phenomena that produced the signal.

[1] Available for Matlab platform in [26]

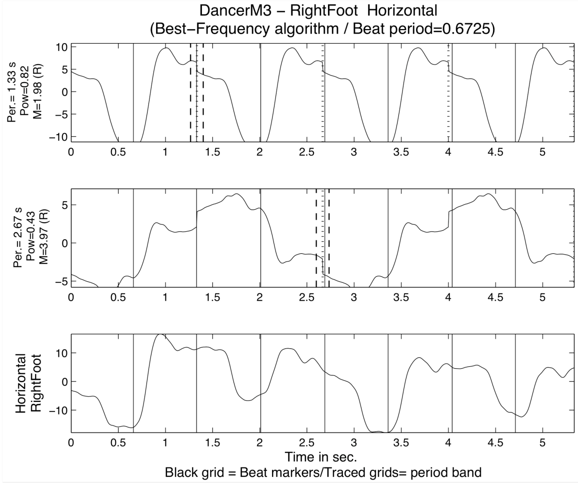

Fig. 2. Signal (bottom part) and periodicities (upper parts) resulted from the analysis using Sethares's Best-Frequency Algorithm. Both periodicities found are relevant (bar and double bar music metric layers). Periods (Per.), energy (Pow.) and metrical level (M) approximations are displayed at the left side of the graphs.

In the next section, we propose that the selection of the list of periods in dance movements can be based on the metrical properties of the music.

A.I Best-Route algorithm

One of the most interesting characteristics of the PT method is that different configurations (order and elements) of the list of periods to be projected lead to different results. The lack of orthogonality makes the definition of *a priori* rules that govern the heuristic of the algorithm very relevant. If the heuristics that govern the list reflect the nature of the periodic behavior of the signal, the algorithm tend to be more efficient in detecting relevant periodicities. In the case of Samba dance, we assume two simple conditions: (1) that dance movements are clearly distributed over the musical metrical layers (they may reflect these layers and provide synchronized or counterpoint movements in relation to musical sound), and (2) that large movements will be more relevant than small ones.

By applying these principles, we designed an algorithm, called the *Best-Route* algorithm, that computes a list of the most powerful periods that fall near the periods of the metrical layers. In this study we defined the metrical layers as the following grid of factors of the musical beat: 0.25, 0.33, 0.5, 0.66, 1, 1.5, 2, 3, 4. The pseudo code of this algorithm can be described as follows:

Pick number of samples N of the signal x, metric grid *ml* and threshold $th \in (0,1)$;

FOR $p = 1,2,3...,N/2$
    PROJECT each *p* periodicity onto the subspace x_p
    STORE the norm of each periodicity in *Pn*
END
SELECT a descendent list of peaks of *Pn* to *Pp;*
RETRIEVE the periods of *Pp* to *L;*
FILTER periods in L that fall near any value of *ml;*

FOR each period of *L*
    LET $r = x$
        PROJECT periodicity onto the subspace x_p
        WHILE periodicity norm > threshold *th*
            STORE basis, norm and period
        REMOVE basis from the signal leaving
            residue $r_p = x - x_p$
        END
    END
END

B. Identification of musical and choreographical relevant features

The identification of musical and choreographical relevant features aims at setting the general framework for sonification. We propose to use minimal transformations in the repetitive movement from dance to generate music textures and then check stylistic correspondences. Inspired by the fact that that humans can also perceive and use patterns of velocity and acceleration to infer and coordinate movement [27], we extended the displacement (D) representation of periodic movements to its respective velocity (V) and acceleration (A) differentiations.

A minimal set of transformations guarantee that the rhythmic features that could emerge from the movement are likely to be perceived by the dancer in the performance and maintain a interesting high indexicality [see discussion in 28, p. 213]. More specifically, we assumed that changes in the directions of displacement, velocity and acceleration patterns could be more accessible for the dancer or observer. Assuming that both bottom and upper limits of the movement vectors can be perceived, we marked all occurrences of peaks and valleys of the signal by detecting local maximums and minimums above a delta threshold of 0.05 of the normalized (0-1) signal. These occurrences defined the attack points for the sounds in the sonification. Fig. 3 displays the 3 vectors (displacement, velocity and acceleration patterns) generated from this process and its respective event points. Peaks are represented by cross markers while valleys are represented by circle markers.

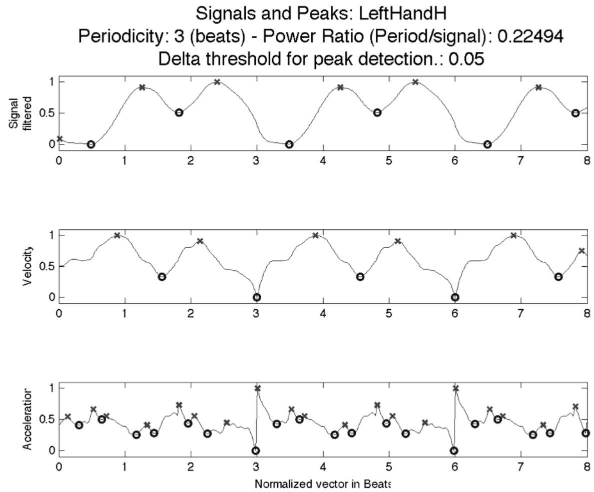

Fig. 3. Displacement, velocity and acceleration vectors. Crosses indicate peaks (or local maximums) while circles represent valleys (or local minimums).

C. Setting the rules to reconstruct music

The last problem has to do with the musical choices we have to make in order to sonify the resulting patterns.

Several sources characterize Samba music as binary, multilayered polymetric rhythmic structure [6]-[4]-[13]-[5]. The music patterns show a strong tendency towards binary accentuations (mostly melodic), even though the lower percussion and instruments layer tend to “damp” the first beat in the binary bar. Polymetric and polyrhythmic patterns are often verified along different metrical layers and syncopation performed by mid-range instruments. Accentuations in high frequency instruments also perform recurrent syncopated patterns and rhythmic models. Tatum figures are commonly found in high-pitched instruments while the beat grid is often not represented by a single instrument (see Fig. 4 for an example). Some traditional rhythmic figures found in samba are the Characteristic Syncope, Tresillo and Habanera figures [5].

Therefore, we searched for similarities between these rhythmic characterizations and the movement patterns using visual inspection. By doing this, we were able optimize the mapping of the musical texture and attach a corresponding sound sample to each characterized rhythmic movement. This procedure, which is generally subjective and context based, improves the musical choices necessary to proceed with the process of sonification [see discussion in 28, p. 211].

D. Evaluation method

The evaluation of the sonification was performed by Samba experts (Brazilian musicians) who took part in the research, in a continuum and exploratory mapping-evaluation cycle. Onsets of the successful sonification patterns can be further compared with symbolic patterns described in scientific literature (for an example, see Fig. 6) or with onset patterns extracted from the music that accompanied the dancer (displayed in

Fig. 4). Such procedure reflects the exploratory concept of this study and leaves the evaluations opened for other re-significations of dance patterns in other styles, multimedia art-works and other studies. So far the presentation of the methodology, in the next section we focus on data collection in a concrete study.

IV. DATA COLLECTION

A. Movement tracking

The dance sample analyzed was performed by a Brazilian professional male dancer and teacher, using Samba music chosen from his own repertoire. The instructions for the dance performance were (1) to dance *Samba-no-Pé* style, (2) perform homogeneous and simple dance steps, (3) and to organize the performance in 3 phases: (a) frontal and (b) lateral presentation to the camera, and (c) improvisational presentation. Although the video recordings do not reflect the spontaneous way of the real context, the professional experience of the dancer may compensate for further ecological problems. Samba dance professionals which perform these activities may have developed a better “body image” of the dance form, a deep awareness differences compared with other dance forms, a more clear and non disrupting understanding of objective tasks and professional competence to demonstrate Samba dance forms. This reduces the interference of improvisations, errors and personal characteristics. In this study we only concentrate in homogeneous excerpts, danced in frontal presentation and with a length of 8 musical beats.
The music excerpt selected by the dancer was “*Do jeito que a vida quer*” (composer: Benito Di Paula [2], mean BPM = 89.21).

Fig. 4 shows the results of onset pattern detection applied upon a set of 40 auditory filter bank decompositions over the music excerpt[3]. Although this example does not represents all characteristics of the style discussed in the scientific literature, it is possible to observe some characteristic structures such as Tatum layers (higher channels), bass drum beat onsets (lower channels) and polyrhythmic structures (mid-channels).

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[2] João Nogueira & Paulo Cesar Pinheiro - *Parceria* - 1994
[3] Onset detection was based in IPEMToolbox for Matlab [29]; the auditory model was described in [30].

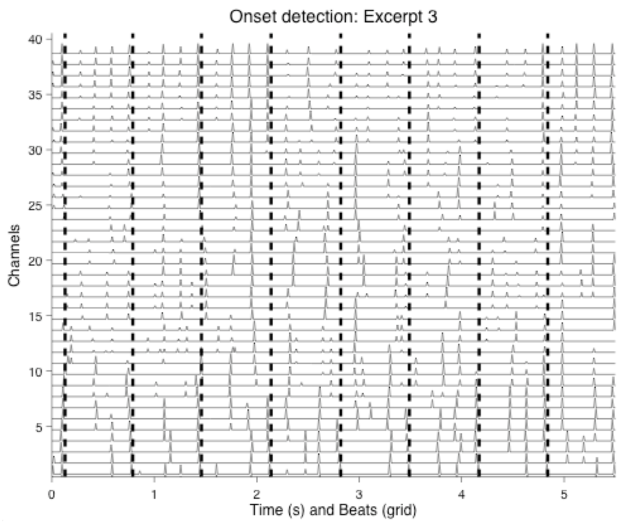


Fig. 4. Onset detection of 40 auditory filter bank applied over the music excerpt. Traced lines indicate beat points.

The trajectories of 9 body points in the visual 2 dimensional plane of video were determined manually, using manual movement tracking [see 31, 32]. This technique, although time consuming, has been used in ethnographical studies and in speech analysis. It consists of marking and recording 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 hip, hands (left and right), knees (left and right) and feet (left and right).

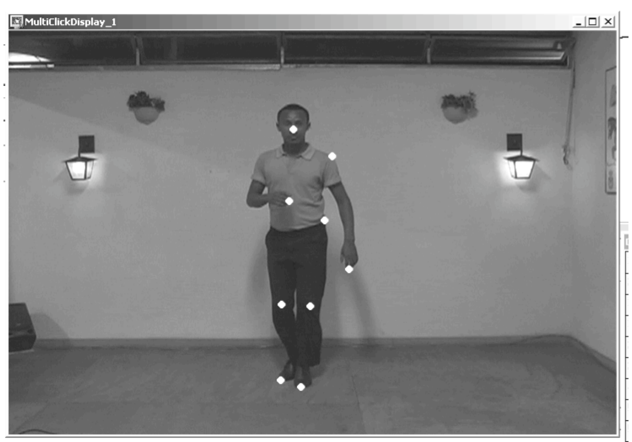


Fig. 5. Frame-by-frame manual tracking. Each white dot represents one position marked with the mouse using visual identification (the size of the points shown here is bigger than the original to facilitate visualization). The original patch offers a visually recognizable mark definition of 1x1 pixel along a spatial definition of DV format (720x480 pixels).

A set of 18 vectors (2 x 9 body part) was generated with the same temporal definition and spatial resolution of the video format (30 frames/second of temporal resolution and 720 by 480 pixels of spatial resolution for the entire image). The video recordings were realized using a 3CCD Mini-DV camera and professional microphones, registered in DV-NTSC format at 30 fps and audio resolution at 48000 samples/s. The procedure shown in Fig. 5 was performed using a specific patch in Eyesweb [33] platform.

V. Analysis and Sonification

The analysis of the trajectories was implemented using Matlab, while the sonification was performed using PD [34] (aka Pure Data). This workflow allows the combination of rapid algorithm development in Matlab programming with real-time diagnostics of results in PD. Both horizontal (H) and vertical (V) components of the 9 trajectories were processed applying the following sequence of procedures:

A. Signal preparation
   a. Segmentation
   b. Resampling
   c. Filtering (low pass)
B. Extraction of Patterns
   a. Extraction of Best periodicities
   b. Generation of Velocity and Acceleration patterns
   c. Filtering (low pass)
   d. Detection of peaks
C. Sonification
   a. Analysis of rhythm structures
   b. Sonification

A. Signal preparation

We segmented the dance patterns in such a way that they corresponded to 8 musical beats (4 bars), in order to have a precise representation of the dancer behavior in at least 4 bars. The beat markers and mean beat period used to calculate metric layers from music were extracted using manual inspection of beat tracking with the software Beatroot [35].

The signal corresponding to these patterns was then resampled to 768 samples in order to have proper highly factorable integer as total sample. As described in Sethares and Staley [20, p. 2961] this procedure optimizes the performance of the algorithm by improving the detection of expected periodicities, in this case, metric layer periods[4]. A low pass filter was also applied to the signal in order to eliminate natural tracking deviations from the manual annotation. The signal was also subtracted by its mean in order to avoid the interference of the pixel position as a linear trend, which practically results in non-relevant powerful periodicities of length=1 sample in the results.

B. Extraction of patterns

We applied the *Best-Route* algorithm described above to the dance signals. This algorithm outputs periods, power extracted from the signal and the basis (or waveform) of the periodicity detected. To compute the metric layer's periods, we used the mean beat period of the danced music expert multiplied by the following metric rule: 0.25, 0.33, 0.5, 0.66, 1, 1.5, 2, 3, 4. These factors, when multiplied by a mean beat period, give the period of each metric layer. This metrical rule comprises not only significant metrical grids as the beat (1), bar (2) and Tatum (0.25) layers, but also more complex or contrasting meter possibilities (0.33, 0.5, 0.66, 1.5, 3, 4). A flexible bandwidth of +-10% of the mean beat period was arbitrarily applied to each metric period. The algorithm iterates as described in the section III.A until the last periodicity represents less than 1% of the signal norm.

In this study, only the most powerful periodicity was selected, although the artistic and musicological explorations of other periodicities or PT algorithms may be interesting to examine as well. From each best periodicity displacement (D) we generated velocity (V) and acceleration (A) patterns. Due to the fact that relative magnitude differences between movements of body parts are not relevant in this study, we normalized the range and amplitudes of the signals to 1 (range 0-1) in each pattern (D, V and A).

Finally, we detected the time points of the dance periodicity patterns that could mark the onset points in the synthesis. Although dancers could hypothetically feel the rhythm attack point in different points along the movement cycles, we decided to rely on simple solutions such as the local maximum and minimum of the periodicities. Therefore three possibilities of "attack" points were defined: (1) peaks or local maximum of the normal signal, (2) valleys or local minimum or (3) both local minimum and maximum peaks concatenated.

From each original displacement signal we generated 9 text files, namely, 3 pattern variations D, V, A in three kinds of patterns: p-peaks, v-valleys and a-all (peaks and valleys), that could be read by PD, and then trigger sound samples.

C. Sonification

To improve the combination of the patterns and instrumental textures, the set of 162 onset patterns (18 segments * 3 signals * 3 onset possibilities) was inspected in order to find similar rhythmical structures present in the Samba music. The presence of rhythmic figures such as Tresillo, Charactheristic Syncope, Habanera, rhythmic qualities such as syncopated patterns, and metrical grids such as beat and bar are displayed in the Table 1.

The map was linked to a limited to a set of 4 simultaneous rhythmic sequences (sound tracks), which can be easily loaded in a patch developed in PD software. The sound samples used in this study were limited to 6 different percussion samples, comprising 2 different sound variations of traditional Samba ensemble instruments: *Surdo* (open and damp), *Tamborim* (small frame drum) and *Ganzá* (high pitched shaker). This patch (not shown here) allows to explore all combinations of patterns, attach sounds, modify BPM of the sequence and other possibilities such as noise modulation, amplitude modulation of sound samples, gain controls, looping, fast sound bank switching.

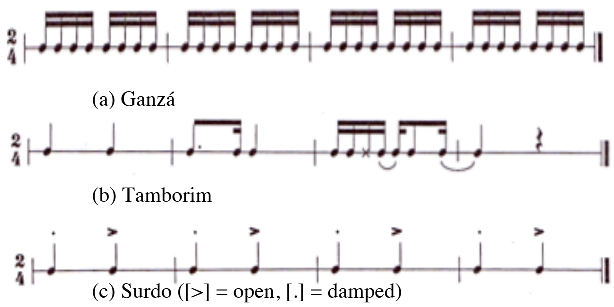
VI. SONIFICATION RESULTS

There were no relevant periodicities detected for the horizontal component of the nose segment. This segment, together with shoulder, knee and hips were particularly subjected to deviation errors in the manual tracking, which may have resulted in random noise artifacts in the signal. This effect may reflect problems during the detection of non-precise "points" in the natural silhouette. The shoulder, for example, is not a clear point defined in the body anatomy, but a round contour extending from the clavicle to the forearm. Although this erratic process is a result of manual tracking process it interestingly emulates the lack of "precise" results, which are compensated by the relevance of the ecological approach.

Each mapping configuration was implemented in 4 simultaneous tracks, which are an acceptable dense ensemble for percussive Samba music. Such texture gives a good balance between complexity and clarity in the rhythmic stream. In order to optimize the different possible mappings, we first defined selected possibilities using 2nd beat rhythmic structures (displayed in Table I) to trigger low-frequency *Surdo* samples, which are one of the most constant rhythmic patterns in the Samba ensemble. In the sequence, we mapped Tatum layer patterns, which are normally and constantly performed by high-pitched

[4] The sample length of 768 samples can be factorized by integers sample intervals when divided by metrical subdivisions such as 8 (number of beats in the vector), 2, 3, 4 (bar layer), 6, 12, 16 , 12, 24 (Tatum layer), etc.

instruments like the *Ganza*. The most diverse structures were tested in the mid frequency instruments, which are commonly characterized by improvisations and syncopated patterns.



(a) Ganzá

(b) Tamborim

(c) Surdo ([>] = open, [.] = damped)

Fig. 6. Typical Samba texture for the referred instruments extracted from [36]. Note that the Surdo description shows two playing techniques with different sound productions (open and damped), represented in the onset sonification by 2 onset tracks.

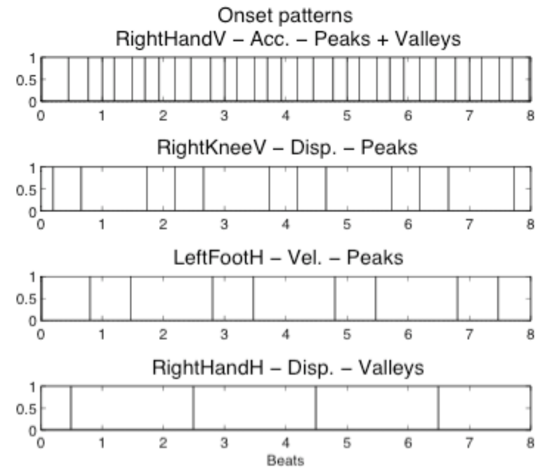


Fig. 7. Onset patterns of the sonification n. 1 displaying respective segments and peak variations.

TABLE I
RHYTHMIC STRUCTURES X BODY SEGMENTS

Body Segments **H= Horizontal** **V= Vertical**	**Best metric layer**	**Power ratio**	**Bar**	**Beat**	**2nd Beat**	**Tatum**	**Generally Syncopated**	**Tresillo**	**Character. Syncope**	**Habanera**
Nose H	**N/A**									
Nose V	**3**	**0.15**					Av, Vp, Vv			
Right Shoulder H	**2**	**0.16**					Dp, Dv, Va, Vp, Vv			
Right Shoulder V	**2**	**0.39**		Av		Aa	Dv,	Vp		
Right Hip H	**2**	**0.11**					Dv	Dp		
Right Hip V	**4**	**0.60**					Vp	Dp, Dv		
Left Hand H	**3**	**0.22**					Dp, Dv, Ap			
Left hand V	**2**	**0.47**	Dp		Dv					
Right hand H	**4**	**0.57**	Vv		Vp					
Right hand V	**4**	**0.73**	Dp	Aa	Dv	Aa				
Left knee H	**2**	**0.51**	Dp		Dv				Vv	
Left knee V	**2**	**0.26**		Dv			Dp			
Right knee H	**2**	**0.28**				Aa	Dv	Dp		
Right knee V	**2**	**0.23**		Vp	Vv		Dv			
Left foot H	**2**	**0.53**	Dp				Dv, Vp, Vv			Ap
Left foot V	**2**	**0.51**	Dv		Dp		Vp, Ap, Av			
Right foot H	**2**	**0.51**				Aa	Dp			
Right foot V	**2**	**0.68**	Dp				Ap			

PATTERNS SYMBOLS:
SIGNALS: D=DISPLACEMENT, V=VELOCITY, A=ACCELERATION
PEAK DETECTION: P= PEAKS (LOCAL maximum), v= Valleys (local minimum), a= all (both Local Max and Min)

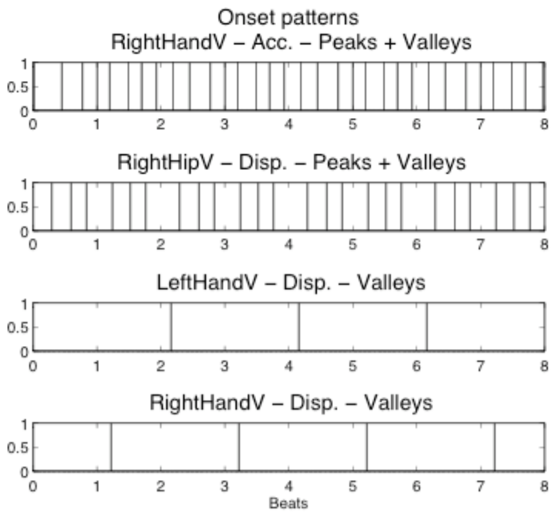


Fig. 8. Onset patterns of the sonification n. 2 displaying respective segments and peak variations.

VII. DISCUSSION

A. Detection of periodicities

Although this exploratory study was not designed to analyze the performance of the algorithm, nor to delineate broad assumptions about the Samba dance forms, some promising results were found concerning both fields. The periodic patterns extracted using our algorithm show consistent results when compared with expected repetitions of the dancer's behavior and the overall shape of the repetitive gestures. The best periods for the movements in Table I demonstrate that the mode of the powerful repetitions is highly concentrated in 2 beat periods, which confirms the characterization of Samba as a binary bar form. Such parallelism is also validated by observations made in [9]-[37]-[38], which suggested the possibility (or necessity) to define meter through dance or body movements. These studies assume that meter is an emergence of corporeal engagement.

Another fundamental property of this algorithm is that it outputs its own basis (waveform). Instead of representing movement by means of frequency and phase (e.g.: Fourier methods), representation of body movement seems to be much better described by means of period and basis, or more clearly, time and trajectory in the space. Our analysis shows that metric layers from music provide a suitable tool to look at dance gestures. Conversely, one could say that Samba dance allows this metric analysis possible because the metric layers are mirrored in the dance.

B. Selection of rhythmic structures

The recognized rhythmic structures displayed in Table I were successfully sonified in several variations of percussion musical textures. Although not all combinations result in good rhythmic textures or fit into a recognizable Samba structures, some of them showed interesting rhythmic similarities. It is of interest to further analyze systematically which ones fit and which ones don't fit. However, automatic processes that could perform the analysis of style or similarity are currently too complex to be discussed in the present paper.

An overall subjective evaluation of these textures is that Samba style is recognizable in the sonification, but it is clear that rhythmic patterns are not completely "correct". Deviations of expected thetic attacks suggests imprecise playing, while short period repetitions in the mid-frequency range (mostly 2 beat length repetitions in the 2nd and 3rd tracks) disrupt the natural flow. Samba musicians tend to improvise large percussion phrases in the mid-range while high and low instruments sustain shorter rhythmic formulas and predicable phrasing. Rhythmic patterns sound natural, since patterns are linked with human movements, but the lack of accentuation profiles gradually changes the perception of the sequences into an artificial compound. The combination of other patterns to shape accent profiles and the development of simple "thetic" rules to shift attacks globally or locally are examples of "low cost" solutions that could improve the sonification.

Other tendencies such as the concentration of onsets coming from displacement patterns (D) in the metrical grids (beat, bar, etc.) and large movements (hands and feet) show the metrical basis being powerfully structured in the choreography, and perhaps in the dancers perception of metrical structures. The tendency of other subtle body elements, such as hips and knees, to generate faster rhythmic onsets, and specially the emergence of diverse syncopated patterns along the velocity and acceleration patterns may give us a clue for further exploration of hidden body rhythms that could mirror or flourish in music patterns. Many of these general syncopations seem to be correlated with other less traditional rhythmic figures cited in the bibliography. But this verification would demand other analytic methods due to its variations and combinatory possibilities.

VIII. CONCLUSION

We developed a multi-modal analysis-by-synthesis method for the study of Samba dance and music. The method draws on the periodicity analysis of dance movements, using musical metrical layers to improve the heuristics of the Periodicity Transform analysis. Starting from the found periodicities in the dance patterns, it was possible to re-synthesize traditional rhythmic structures of Samba music. The application of this multi-modal analysis-by-synthesis method to Samba music and dance leads to results that are practically and theoretically significant. The emergence of musical rhythmic textures that could be directly mapped to music samples is surprising, giving the high level of indexicality, and the complexity of cognitive processes that could be involved in the phenomenon. The results of the present study suggest that dance patterns embody the musical meter but further work is needed to deploy the method to more dance samples and to better understand the mediating role of the human body in mirroring and disambiguation processes. While future work will involve a larger sample of excerpts and more precise movement capture, our present results already reveal that artistic exploration of movement streams in music creation, soundtrack, interactive music and other fields are quite promising.

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