WP 3 – Interactive Sonification and Active Music Experience of Dance

D3.2 – Second version of the sonification software libraries

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Introduction

The main aim of WP3 is to identify effective mappings between physical gestures and sound parameters to support feedback and understanding of quality features in human movements. In this context, we focus on physical quantities derived by human body movements, from low level features (e.g., accelerations in running) to higher-level expressive qualities (e.g. fluidity of movement), and by human-generated movements (e.g., spatial movement of an object). We implement sound synthesis models for reacting to body movements in a natural way with the aim to map movement qualities into the auditory domain.

The main outcome of this WP is a number of different sound processing and synthesis models that will become the basis for the interactive sonification and active music experience.

1. Preliminary Experiments and Feasibility Studies

1.1 Identification of sound models for the communication of body motion qualitites

1.1.1 Results from a pilot experiment with pre-school children

In order to identify what should be the main characteristics of sound models suitable for communication of body motion qualities, we run a pilot experiment with pre-school children. Detailed description of the experiment can be found in DANCE Deliverables D3.1, and in the paper by Frid et al. (2016a).

As we wrote in D3.1 "We chose children for this first experiment since we wanted to have spontaneous reactions from users to our sound models, since children usually show fewer inhibitions than adults, and it has been shown that they spontaneously move when their hear sound. The main idea with the experiment was to test if the quality of children's motion would vary when the sound generated by their own movements had different acoustical characteristics corresponding to smooth or jerky sounds. In particular, we created three filtered noise models ranging from very fluid (wind-like) sounds to very jerky (choppy, clicking) sounds."

Adapted from the abstract of Frid et al. (2016a): "The experiment consisted of three studies focusing on the effect of different sound models in interactive sonification of bodily movement. We hypothesized that a sound model characterized by continuous smooth sounds would be associated with other movement characteristics than a model characterized by abrupt variation in amplitude and that these associations could be reflected in spontaneous movement characteristics. Three subsequent studies were conducted to investigate the relationship between properties of bodily movement and sound: (1) a motion capture experiment involving interactive sonification of a group of children spontaneously moving in a room, (2) an experiment involving perceptual ratings of sonified movement data and (3) an experiment involving matching between sonified movements and their visualizations in the form of abstract drawings. In (1) we used a system constituting of 17 IR cameras tracking passive reflective markers (Optitrack Prime setup, controlled by the Optitrack Arena software). The head positions in the horizontal plane of 3–4 children were simultaneously tracked and sonified, producing 3–4 sound sources (i.e. one per child) spatially displayed through an 8-channel loudspeaker system. We analyzed children's spontaneous movement in terms of energy-, smoothness- and directness-index. Despite large inter-participant variability and group-specific effects caused by interaction among children when engaging in the spontaneous movement task, we found a small but significant effect of sound model. Results from (2) indicate that different sound models can be rated differently on a set of motion-related perceptual scales (e.g., expressivity and fluidity). Also, results imply that audio-only stimuli can evoke stronger perceived properties of movement (e.g., energetic, impulsive) than stimuli involving both audio and video representations. Findings in (3) suggest that sounds portraying bodily movement can be represented using abstract drawings in a meaningful way. We argue that the results from these studies support the existence of a cross-modal mapping of body motion qualities from bodily movement to sounds. Sound can be translated and understood from bodily motion, conveyed through sound visualizations in the shape of drawings and translated back from sound visualizations to audio. The work underlines the potential of using interactive sonification to communicate high-level features of human movement data.”

1.1.2 Sonification models

Three sound models based on filtered white noise were defined for this experiment. One with very fluid, wind-like, sounds (S1); one middle model with somewhat jerky sounds (S2); and one with very jerky, choppy and clicking sounds (S3). The choice of these sounds was based on previous research results as reported in D3.1 (Hansen et al. 2012, Dubus 2012; Dubus & Bresin 2015). For each sound model, low-level movement parameters (velocity and x- and y-position of the subject) were mapped to acoustic parameters.

Sound model 1 (S1) was achieved by filtering white noise using the MaxMSP resonance filter `biquad~` object with mode “resonant”. Velocity magnitude of participant's movement in the 2D-plane was mapped to center frequency of the filter (50 to 1100 Hz) and to Q-factor (1.8 to 4.0). Amplitude modulation of the filtered signal was carried out using the `rand~` object, with input parameter 3 Hz. Finally, velocity magnitude was logarithmically scaled to amplitude of the signal, so that no sound was heard when the participant did not move. Sound model 2 (S2) was implemented in a similar manner as S1, with the difference that the resonance filter's center frequency was set to 100–900 Hz and Q-factor range was set to 0.1–0.3. Amplitude modulation was also increased to 18 Hz. The final sound model (S3) was also based on filtering white noise, but was implemented using a band-pass filter (object `biquad~`). Just like for the other two sound models, velocity magnitude was mapped to the center frequency (100–3000 Hz) and Q-factor (0.01–0.6). Amplitude modulation was achieved by triggering peaks using the `curve~` object which produced a non-linear ramp of length 250 ms, triggered every 50 to 800 ms, depending on velocity. See Figure 1 for the spectral content of 2 min of sound models S1, S2, and S3.

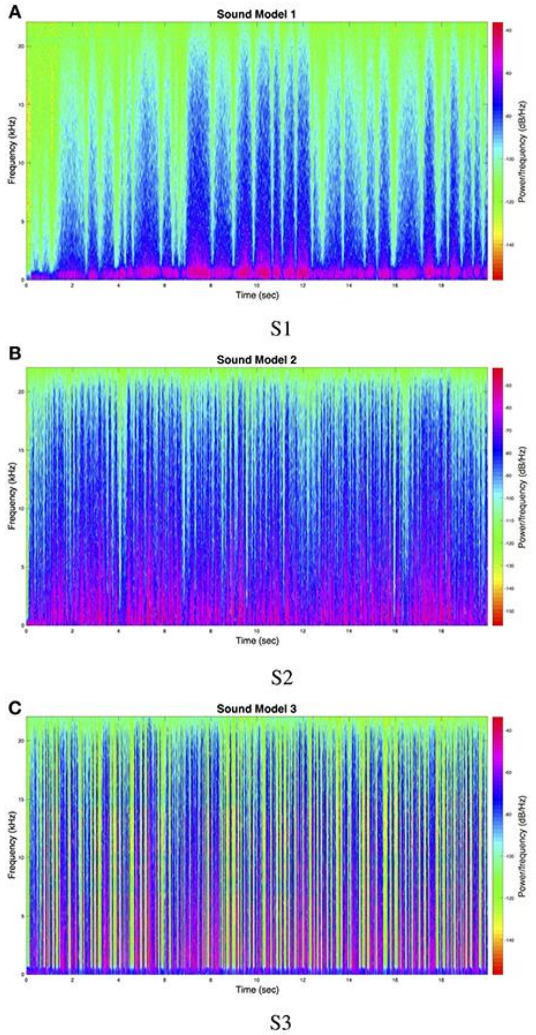

Figure 1 Spectral content of 2 min of sound models S1, S2, and S3.

1.1.3 Studies

We conducted three studies for testing the effects of the three sound models S1-S3 on body motion qualities and perception.

Study 1: Motion Capture Experiment. In this study we investigated how the three sound models influenced movement characteristics among children when moving freely in a room. Our hypothesis was that the specific sound model used at a particular time point could influence spontaneous movement of the children at a specific point of measurement. To investigate this hypothesis, data of participants' movements was collected in a motion capture room. The x- and y-position and velocity of each participant were tracked. This data was sonified in real-time providing feedback of the performed movements.

Study 2: Perceptual Rating of Audio and Video. The second study focused on investigating if sound models used in Study 1 could communicate certain hypothesized movement qualities. We therefore ran an on-line perceptual test in which sound generated by children in Study 1 were rated by listeners along six different perceptual bipolar scales, Fluid, Energetic, Impulsive, Fast, Expressive, and Rigid.

Study 3: Perceptual Rating of Sound Visualizations. In the third study we hypothesize that the properties of the body motion used by the children for generating sounds S1–S3 in Study 1 can be found also in abstract representations of sound, i.e., sound visualizations in the form of drawings made by children while listening to excerpts of sounds S1-S3. Our hypothesis was that there is a consistent mapping of body motion qualities from one modality (sound) to another one (sound visualization). We therefore ran an on-line experiment to see if participants could match recordings of one sound model to its corresponding abstract visual representation (i.e., a drawing).

1.1.4 Results

The results from the three studies presented above suggest that sound models can be designed and controlled so that: (1) sound might have an effect on bodily movement characteristics; (2) different sounds can be associated with different levels of motion qualities (e.g., fluid and expressive); (3) sound-only stimuli can evoke stronger perceived properties of movement (e.g., energetic, impulsive) compared to video stimuli; (4) sounds generated by body motion can be represented and associated with sound visualizations (drawings) in a meaningful way. The results obtained support the existence of a cross-modal mapping of body motion qualities from bodily movement to sounds and the potential of using interactive sonification to communicate high-level features of human movement data. Sound can be translated and understood from bodily motion, conveyed through sound visualizations in the form of drawings, and translated back from sound visualizations to sound. A more extensive and detailed presentation of the results from the three studies can be found in Frid et al. (2016a).

1.2 Sonification of movement qualities: energy, fluidity, weight, and impulsiveness

In parallel with the analysis of the results produced in the children experiment described in the previous section (Frid et al, 2016a), we continued with experiments and trials in public events and workshops as successfully done in in the previous reporting period (see D3.1, events at SONAR+, Barcelona 2015, STARTS Workshop, Brussels 2015, and Festival della Scienza*,* Genoa 2015).

During year 2016 we have continued to design a variety of synthetic acoustical models for the sonification of movement qualities energy, fluidity, weight, and impulsiveness discussed in D3.1. The research effort during 2016 has focused specially on the sonification of fluid/rigid movements. This has resulted in a number of sonification techniques that have been evaluated in experiments with participants and presented in publications, in workshops and at international conferences (Alborno et al, 2016; Camurri et al, 2016; Frid et al, 2016b; Piana et al, 2016a, 2016b).

KTH has acted as co-organizer of the 5th ISon - Interactive Sonification workshop[1], held in Bielefeld in December 2016.

KTH and Genova has also organized a three-hour tutorial at ISon with "**Interactive Sonification of Body Motion Qualities**" as theme[2] (see Annex 1 for a description of the tutorial). Participants to his hands-on tutorial on the interactive sonification of body motion qualities were provided data from motion capture recordings of dancers moving with different qualities (e.g. fluid, rigid) in three different formats, videos, data files, and real-time streaming via OSC. Participants (1) came up with own sonifications of motion data provided by using their own sonification tools, (2) identified and discussed sounds which best represent the body motion qualities represented in the provided videos (e.g. fluid, rigid), (3) fine-tuned existing sound synthesis models (provided at the workshop by KTH) by real-time manipulation of their parameters.

Results gathered from participants activities at the ISon tutorial will help in refining the sonification models of fluidity presented at the same conference by KTH and Genova (Frid et al, 2016b; Alborno et al, 2016), and summarized in the next section. This refinement will be done by integrating the KTH and Genova systems and by running new perceptual experiments with users. Final sonification models and results will be included in two papers to be published during 2017 by project partners KTH and Genova.

Overview of studies on the sonificaiton of *fluidity* during year 2016.

During 2016 we focused on fluidity in a number studies conducted and documented in international publications. Fluidity has been used as a case study towards the development of a solid sonification methodology of other movement qualities, such as energy, weight, and impulsiveness previously described in D3.1.

In a work presented at CHI 2016, Piana et al. (2016a) presented a framework and an experimental approach to investigate human body movement qualities (i.e., the expressive components of non-verbal communication) in HCI. They first defined a candidate movement quality conceptually, with the involvement of experts in the field (e.g., dancers, choreographers). Next, they collected a dataset of performances and evaluated the perception of the chosen quality. Finally, they proposed a computational model to detect the presence of the quality in a movement segment and compared the outcomes of the model with the evaluation results. They applied this approach to Fluidity. Main results of this work are (1) a new definition of full-body movement fluidity based on the perceptive evaluation of professional dancers' performance, and (2) an algorithm based on mass-spring-damper model to detect the presence of fluidity in movements.

At the same conference (CHI 2016), KTH took active part at a workshop organized by members of five different universities (including KTH) for the establishing of a Special Interest Group (SIG) for bridging the gap in research on body sensing, body perception and multisensory feedback (Singh et al., 2016). The main goals of this SIG were to lay common ground for the research and design of multisensory feedback and to foster a community of researchers working on such technology across HCI. The workshop provided the opportunity explore the research areas in relation to existing theories, methods, and technologies, to map the space of design problems and promising solutions relevant to research and practice, and to identify challenges, and strategies to approach them, when studying and designing such systems. Foreseen activity after the SIG meeting is to continue to build a multidisciplinary network for studying and designing multisensory feedback technology (e.g. build an email list, dedicate a website to the community, start a group on Facebook, organise regular workshops, publish special journal issues, and promote grant/project collaborations). This is expected to foster communication and collaboration among researchers, promote more awareness of research and practice from different domains, leading to a more comprehensive understanding of design and evaluation of multisensory technologies.

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[1] ISon 2016: http://interactive-sonification.org/ISon2016/

[2] ISon 2016 tutorial: http://interactive-sonification.org/ISon2016/#tutorial

At ISon 2016, Genova presented an algorithm to detect fluidity in full-body movement, and a model of interactive sonification for conveying fluidity through the auditory channel (Alborno et al, 2016). A set of different sonifications was developed: some followed the proposed sonification model, and others were based on different, in some cases opposite, rules. The hypothesis was that the proposed sonification model was the most effective in communicating fluidity. In order to verify the hypothesis, we developed a serious game and performed an experiment with 22 participants at MOCO 2016 conference[3].

The sonification model proposed was based on granular synthesis since it easily allows to change the basic sound materials (buffers) for obtaining a wide timbral variety. The model is parametrized as follows:

- Fluidity index FI to detect fluid movements, on a large temporal scale (1-3 seconds).
- Kinetic Energy EI to detect little, short and fast changes in the movements which otherwise would not have been considered by FI, potentially causing a lack of synchronization between the visual flow and the sonification.

Seven different sonification variations of the model were tested in a game: they differed in the type of buffer ("ideal" or "wrong/contrasting") and type of mapping ("good" or "bad"); "ideal" buffers have been designed to comply with the description of fluid sounds given in the previous section. On the contrary, "wrong" buffers have been designed following the opposite criteria. "Good" mappings were characterized by smooth transitions and continuity while "bad" ones used steps and discontinuities (for more details see Alborno et al, 2016).

An entire game session consisted of listening to the seven sonifcations produced from a pre-recorded short dance performance (not visible to the participants). While listening, each player was asked to move freely following what they listened to. Players were not aware of the origin of the sonic material they listened to. To avoid mutual influence between the players and to increase their sensitivity to auditory perception they were blindfolded before starting the experiment. Results from the game confirmed the validity of the sonification model proposed: sonifications based on "ideal" buffer and "good" mapping obtained significantly higher score and seemed to be more effective in helping participants to match the original movement fluidity expressed by the dancer).

Also at ISon 2016, KTH (see Frid et al., 2016b) presented two experiments for investigating potential strategies for sonification of the expressive movement quality fluidity: one perceptual rating experiment (1) in which five different sound models were evaluated on their ability to express fluidity, and one interactive experiment (2) in which participants adjusted parameters for the most fluid sound model in (1) and performed vocal sketching to two video recordings of contemporary dance. The videos are part of the DANCE multimodal repository (Piana et al, 2016).

The five sound models were:

SM1 An open chord, Eb, in five octaves with one added fifth in the middle of the octave stack, made of saw wave oscillators with variable pitch stability, from perfectly stable to a random modulation of 50Hz centered around the pitch, summed and filtered using a 24dB per octave low pass filter with variable cut off frequency. Increasing the energy increased the filter cut off frequency and increasing the fluidity decreased the amount and speed of the pitch modulation.

SM2 A sinusoidal carrier oscillator with a variable amount of phase modulation from three sinusoidal modulators in intervals of unison, two octaves, and two octaves and a fifth. An increase in energy increased the pitch of all oscillators and the modulation index. A decrease in fluidity injected a white noise component into the sum

[3] http://moco16.movementcomputing.org/

of the modulators, destabilizing the pitch of the carrier as well as introducing noise in the final output.

SM3 A complex source-filter-model that aims to simulate a wind sound. A mix of noise sources is filtered through a set of band pass and low pass filters that both respond to changes in the energy parameters but also individually vary their cut off frequencies using low frequency random signals. An increase in energy increased the frequency of the random modulations to the filters cut off frequencies as well as their center frequencies. An increase in fluidity resulted in smoother shapes in the modulation signals, as well as a smoother, less coarse, mix of noise sources.

SM4 A simple source-filter-model using a mix of smooth and coarse noise sounds filtered through a 24dB per octave low- pass filter. An increase in energy increased the cut off frequency of the filter. An increase in fluidity increased the amount of smooth noise in the source mix.

SM5 White noise processed by a bank of parallel bandpass filters, with variable tuning quantized to semi tone steps in a equal temperament scale, and variable resonance. An increase in energy increased the cut off frequency of the filters, maintaining their harmonic relationship. An increase in fluidity increased the q-value of the filter, making it narrower, approaching a sinusoidal wave. A decrease in fluidity made the filter wider, resulting in a noisier output, and also added a detuning component independently to all filters, making the result less harmonious.

In Experiment 1, a significant effect of sound model on perceived fluidity was observed, with sound model SM5 being perceived as significantly more fluid than SM2 and SM3. We believe this to be a result of SM5 representing a complex and layered approach that combines several strategies to express the variations in fluidity.

In Experiment 2, when the participants manipulated the internal parameters of SM5, they tuned the model in significantly different ways in the fluid and non-fluid conditions. This indicates that the parameter space provided offered distinctly different sonic possibilities. In general, significantly larger values were found for the non-fluid condition compared to the fluid one for slider S2 (which controlled the high frequency content in the noise source).

The main conclusion drawn from examining the logged data in Experiment 2 is that participants managed to create two distinct sonic representations. In general, the fluid recordings occupied a lower register and were characterized by a darker or more muffled timbre, whereas many of the non-fluid recordings were characterized by a higher spectral centroid and more noise.

In the qualitative interviews in Experiment 2, the participants conceptualized fluidity (both in movement and in sound) as a property related to water, pitched sounds, wind, and continuous flow. Non-fluidity on the other hand had connotations of friction, struggle and effort. However, the biggest conceptual distinction between fluidity and non-fluidity was the dichotomy of nature and technology, natural and unnatural, or even human and unhuman. We believe that it is important to take these distinct connotations into account when performing perceptual studies focusing on the fluidity parameter.

Some general differences could also be observed in the vocal sketching in the fluid and non-fluid conditions: fluidity was ex-pressed using continuous, softer, and lower pitched sounds with a darker timbre; non-fluidity was vocalized with louder, more strained, creaks and bursts of sound, with more high frequency content. The vocal sketching served two important functions. Firstly, it corroborated the analysis of the interview. Secondly, it provided a possible explanation for the heterogeneity in the resulting audio recordings for the non-fluid condition, as the participants sketched sounds that simply were not possible to arrive at given the possibilities offered by SM5.

2. Planned work

We are planning two final papers on the interactive sonification of fluidity.

One paper will be authored by KTH as a follow up of the ISon 2016 paper (Frid et al., 2016b). In this paper we will:

- Integrate results from the workshop that we organized at ISon 2016 (see Appendix 1)
- Run a listening test where sound stimuli are extracted from music compositions. We will use excerpts from acoustic, electroacoustic and electronic music compositions that have a reasonably similar instrumentation but still have distinctly different expressions. These will be selected on the basis of the categories established in the Ion 2016 paper (Frid et al, 2016b) to find different degrees of fluidity. Participants to the experiment will categorize the excerpts. Our hypothesis is that if we can find purely musical representations (compositions) that can express the presence or absence of fluidity, results from their acoustical analyze can provide new knowledge about how sonification of complex processes that oscillate between different states (e.g. fluid/non fluid) can be aesthetically appealing and musically engaging.

The second paper on fluidity will present the results of a joint experiment by KTH and Genova to be performed in March 2017. The experiment will make use of KTH motion capture system (17 IR Optitrack cameras), and Eyesweb integrated with the KTH sonification models.

The experiment will have the following procedure:

1. Participants do movement wearing markers (placed on hand, wrist, elbow, arm), generate the sound in real-time while making the movement, then they adjust the sound parameters with sliders and then listen again to the sound (that is, they don't perform these 2 actions simultaneously); they can repeat these 2 steps any number of times they like.
2. Participants come back a second time and listen to the real-time sonification of pre-recorded movements (previously recorded in 1) and adjust the sound parameters with the sliders. The movements to be recorded as input to this part of the experiment should be decided before hand: Fluid Vs. Non-fluid

Expected outcomes of the study are:

1. A method for the definition of a parameter-mapping space (values of acoustic features vs levels of fluidity). The method will allow sound designers to define/design the sonification of other features than fluidity (both in the DANCE project, but in general in the future).
2. Use interactive sonification of fluidity/non-fluidity (or other qualities) as real-time feedback to body movements. For example, the results can show that it is important (or not important) to consider to run different sonification models of a feature (any feature, not only fluidity) depending if the target is the sonification of own gestures or not.

Future work in 2017 includes the integration of more sonification models into the DANCE platform, and the evaluation of sonification model by means of neuroimaging experiments in joint experiment in collaboration with partner MU.

In particular, the sonification models resulting from the collaboration with the choreographer Virgilio Sieni and with the composer Andrea Cera will be experimented with audience members, including blind persons, also in the public events "Atlante del Gesto_Genova", planned 24-26 March 2017 in several places in Genoa (Palazzo Reale, Aula Magna Palazzo Balbi, Oratorio San Filippo, Casa Paganini-InfoMus) with over 150 audience members working as performers since December 2016. Besides the public events, this work will result in further consolidated interactive sonification software modules integrated in the DANCE platform. A paper in preparation will explain this work.

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Annex 1 - ISon 2016: Instructions for the workshop on "Interactive sonification of body motion qualities"

Interactive sonification of body motion qualities

Roberto Bresin (KTH), Emma Frid (KTH), Ludvig Elblaus (KTH), Maurizio Mancini (University of Genova), Stefano Piana (University of Genova)

https://goo.gl/T5V06t

The focus of this hands-on workshop is on the interactive sonification of body motion qualities. We will provide data from motion capture and IMU (Inertial Measure Units) recordings of dancers moving with different qualities (e.g. fluid, rigid) in three different formats, videos, data files, and real-time streaming via OSC.

Three are the main activities that you can choose to work with at the workshop

1. Identify and discuss sounds (for example from freesound.org for) which best represent the body motion qualities represented in the provided videos (e.g. fluid, rigid)

2a. Make your own sonifications of motion data provided by using your own sonification tools

2b. Fine tune existing sound synthesis models (provided at the workshop), by real-time manipulation of their parameters

At the end of the workshop, the sonifications will be presented to all the participants of the workshop.

Workshop organizers: Roberto Bresin (KTH), Emma Frid (KTH), Ludvig Elblaus (KTH), Maurizio Mancini (Univ. of Genova), Stefano Piana (Univ. of Genova).

This workshop is supported by the EU-funded DANCE project [1].

[1] http://dance.dibris.unige.it

Schedule

13:30 Presentation of the workshop

13:40 Task 1

14:00 Discussion of task 1 results

14:15 Presentation of Task 2a & 2b. Definition of the two working groups.

14:25 Task 2a & 2b run in parallel (choose one of the two)

15:30 Presentation of results

15:45 Coffee break

1. Selection and Identification of Sounds for the Communication of Fluid and Rigid Body Movements

Identify a set of sounds that match the body movements of a dancer in two videos (using free online sources, such as e.g. https://www.freesound.org/ or https://soundcloud.com). Try to identify about 3-4 sounds, per video.

Upload your sounds here: https://goo.gl/XKeOMS (name your file *yourname_fluid_X* vs *yourname_nonfluid_X,* where X is the number of the recording) and provide a link to the sound file in this form: https://goo.gl/v5LkpJ

2a. Make your own sonifications of motion data provided by using your own sonification tools

Use your own sonification tools for sonifying motion data provided at the workshop. Data are provided in different ways:

- Real-time via OSC
- Log files of OSC data (tables)

The extracted movement qualities are the following:

Quality	Description	Type and Rage of values (min : max)	Osc Tag
Energy	Kinetic energy estimated on single joints or the entire body	Double 0 : 1	/global/features/energy
Smoothness	Smoothness of a single joint	Double 0 : 1	
Fluidity	Movement fluidity estimated on the whole body	Double 0 : 1	/global/features/fluidity
Lightness	Lightness of movement estimated on single joints or the entire body	Double 0 : 1	
Alignment	Body alignment	Double 0 : 1	/global/features/alignment
Vertical Stretch	Body vertical Stretch	Double -1 : 1	/global/features/stretch
Torsion	Body Torsion	Double 0 : 1	/global/features/torsion

All the features will be broadcasted on port 6666 at 50 FPS.

We also provide log files of the broadcasted streams for those who want to continue working on the sonifications or analyse the data offline (download the data from here). The file is stored as tab separated values, where each row represents a frame, and the columns represent the features that are extracted for that specific frame: the first column represents a timestamp (relative to the beginning of the recording) and the rest contain the values of the various features ordered as presented in the table above (Quality, Energy, Smoothness, Fluidity, Lightness, Alignment, Vertical Stretch, Torsion).

Submit a short explanation of your sound model/platform/synthesis model here: https://goo.gl/USdpSj and upload a sound example here https://goo.gl/Wckktd .

2b. Sonification of Fluid Body Movements

This task focuses on carrying out a replication of an experiment on sonification of fluid body movements. One sound model will be presented together with a video sequence of a dancer performing a movement. The sound model is controlled by motion capture data recorded in parallel to the video; the movement of the dancer in the video is translated into sound. Participants will adjust six sliders on a MIDI-controller which change the properties of the sonification. The outcome of the experiment will be a set of different sounds that can be analysed from a qualitative point of view (what are the characteristics of the produced sounds?) but also quantitatively evaluated.

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