EXPRESSIVE SONIFICATION OF FOOTSTEP SOUNDS

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ABSTRACT

In this study we present the evaluation of a model for the interactive sonification of footsteps. The sonification is achieved by means of specially designed sensored-shoes which control the expressive parameters of novel sound synthesis models capable of reproducing continuous auditory feedback for walking. In a previous study, sounds corresponding to different grounds were associated to different emotions and gender. In this study, we used an interactive sonification actuated by the sensored-shoes for providing auditory feedback to walkers. In an experiment we asked subjects to walk (using the sensored-shoes) with four different emotional intentions (happy, sad, aggressive, tender) and for each emotion we manipulated the ground texture sound four times (wood panels, linoleum, muddy ground, and iced snow). Preliminary results show that walkers used a more active walking style (faster pace) when the sound of the walking surface was characterized by an higher spectral centroid (e.g. iced snow), and a less active style (slower pace) when the spectral centroid was low (e.g. muddy ground). Harder texture sounds lead to more aggressive walking patters while softer ones to more tender and sad walking styles.

1. INTRODUCTION

The strong relationship between body motion and sound production has been researched and documented in recent years. Most of the research in this field has been conducted looking at music performance (for an overview see [1]). Little work has been done in the area of everyday sounds produced by the human body and how they could influence the body action itself. In the work presented in this paper the focus is on the relationship between walking and footstep sounds. The main idea is to investigate if the sound produced by human feet while walking can influence the walk style.

In previous works about footstep sounds it has been shown how different sounds are preferred for walkers of different genders [2], and that when walking with different emotional intentions humans make variations of timing and sound level in the same way as found in expressive music performance [3]. It has also been found that there are timbres of musical instruments which are more suitable for certain emotions [4, 5, 6].

In this work we would like to go a step further, and investigate how the sound produced by the impact of shoes on the ground influences the walking style when walking with different emotional intentions. Our hypothesis is that, within the same emotion, walkers change their walking strategy depending on the impact sound of the shoe on the ground. We therefore designed an experiment that is presented in the following section.

The scientific context of this work is that of interactive sonification [7]: as reported in the following sections, data collected from sensors on the shoes have been used for direct real time control of sound models for the auditory display of different ground textures.

2. EXPERIMENT

An experiment was designed in which subjects were asked to walk with four emotional intentions (happy, aggressive, tender, sad) along a path which emitted footstep sounds corresponding to four different grounds. We choose the four emotions happiness, sadness, aggressiveness, and tenderness mainly for two reasons. First they have been investigated in several studies on emotional expression in music (for an overview see [8]). Second, they cover the four quadrants of the two-dimensional activity-valence space [4], and therefore give a quite comprehensive overview on the use of musical parameters such as tempo, that is one parameter that can be analyzed also in walking.

Figure 1: *Active shoes prototype.*

2.1. Subjects

For the experiment we gathered 16 subjects, 13 males and 3 females of the Italian nationality, with average age 27,875. 13 subjects had a musical background and played an instrument. All subjects listen to music. They were not compensated for their participation.

2.2. Equipment

A pair of prototype active shoes (Figure 1) was used for the experiment. The shoes capture the foot pressure that is used for informing different real-time synthesis models, whose output feeds the shoe-mounted haptic actuators and loudspeakers.

Our prototype relies on simple, inexpensive technology both at the sensing and at the actuation side.

For each shoe (see Figure 2), force sensing is operated by a couple of Interlink 400 force sensing resistors, one set in the front part of the insole, one on the rear part. The force data from both shoes are digitized by an Arduino Duemilanove acquisition board, that cuts off measurement noise in the force values depending on

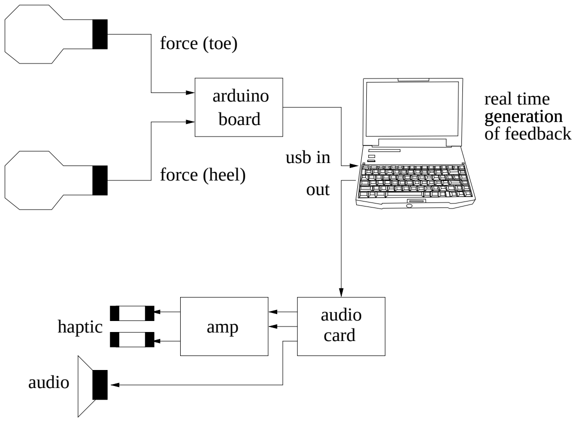

Figure 2: *Connections of physical components realizing one active shoe.*

a threshold, which can be set based on the user's weight and foot size [9].

The digital data are sent, via USB, to a MacBook that generates and conveys the resulting feedback to an RME FireFace 800 eight-channel audio card. From here, the signal goes to a small loudspeaker mounted over each shoe, and in parallel to a conventional stereo audio amplifier, which provides the needed power to form the final output for the haptic actuators, two for each shoe. In total, three signal channels are involved to feed each shoe.

On-shoe small loudspeakers allow for a precise recognition of the sound source position. On the other hand, they cannot emit low frequencies. The haptic actuators compensate for the lack of depth in the sound. By implementing a novel design of recoil-type actuators, they generate vibro-tactile components ranging 40 to 10 kHz, furthermore consume less than 5 W of power to produce thrust up to 5 N, resulting in very high accelerations. Due to their design and structure they can be immersed in the inside of a sole and are able to support the weight of a person [10].

Two subwoofers were placed at the two ends of a 6.8 m long walking path along which subjects were asked to walk, e.g. one subwoofer was positioned at the back of the subject and the other one at the front.

2.3. Stimuli

We used four sounds corresponding to grounds of different nature. Two sounds were directly generated by the foot impact on the ground (real-word textures: wood panels and linoleum floor), and the other two sounds were synthesized by an algorithm triggered by sensors on the shoes (augmented-reality textures: iced snow and muddy ground).

The real-world sound texture for wood panels was realized by putting a catwalk of wooden panels on the floor. The linoleum floor was theoriginal floor of the experiment room. The auditory feedback of iced snow and muddy ground were synthesized in real-time, as explained in the next section, and reproduced by the loudspeakers on the shoes and by the two subwoofers. A video demonstrating augmented-reality sound texture generation and the equipment used for the experiment is available on-line[1].

In the next section we briefly introduce the sound models used for synthesis of iced snow and muddy ground.

2.3.1. *Sound synthesis*

The software used for the synthesis of instantaneous and continuous feedback is a crucial aspect of the system. This software has been coded for the open source real time synthesis environment Pure Data[2]. Due to its flexibility and additional libraries, Pure Data allows to interface the Arduino board directly with the audio card, meanwhile taking in charge of all the needed processing. The patch used for the synthesis of mud sounds accounts for the tuning of parameters for virtual "soft" impacts, each triggered and controlled by the contact force received from the force sensors on the shoes.

All the Pure Data patches used in connection with the active shoes are part of the the Sound Design Toolkit (SDT [11]), a library of ecological synthesis models maintained at the University of Verona, which includes a palette of sound generation algorithms for the virtual display of different floor properties [12].

The experiment involved the synthesis of audio-tactile cues of

- **snow**, rendered by starting from a physically-based model called *crumpling*, that synthesizes in real time granular sequences of elementary hard impact events [13];
- **mud**, resulting from a specific tuning of soft impacts generated in real time.

These attributes are currently object of subjective evaluation, aimed at systematically understanding the sense of realism provided by the active shoes. However, for the purpose of this experiment only the macroscopic differences in the spectral and temporal features between such sounds were of interest, as any reference to the displayed material property was not exposed to the subjects during the walking task.

2.4. Procedure

The way the experiment was conducted was straightforward and the subjects were not introduced into the modality of the experiment. Subjects were asked to wear the active shoes, and to walk along a signed path 6.8 m long in a manner to express a specific emotion. Subjects were asked to walk with happiness, aggressiveness, sadness and tenderness. They did this for each of the four different grounds, wood panels, linoleum, iced snow, and muddy ground, for a total of 4x4 walks. The order of the combinations between emotions and grounds were randomized for each subject.

In order to maximize the possible amount of footsteps, subjects were asked to start their walk using their left foot, and data were logged starting from the first step with the right foot.

Sound examples produced by one subject in all sixteen conditions are available on-line[3].

At the end of the experimental session, subjects were asked about their personal data, and a question about how they experienced the test.

3. RESULTS

The active shoes allow for the logging of the values of several data-driven features. For the purpose of the experiment presented in this paper, five features were logged: heel-to-toe Inter-Onset-Interval (IOI) for both left and right foot, heel-to-heel IOI between right and left foot, toe-to-heel IOI for the right foot, and total footstep number.

First we conducted an analysis of variance. A two-way ANOVA, repeated measures, with the factors emotion and ground

[1] `http://www.youtube.com/watch?v=S3P2lKVDMXk`

[2] `http://www.puredata.org`

[3] `http://www.speech.kth.se/music/papers/2010_RB_ISon`

was conducted on the participants' values separately for each of the five features. Since the limited length of this paper, in the following we present the effects only for factors heel-to-toe Inter-Onset-Interval and heel-to-heel IOI as revealed by analysis. We also discuss the mean values for each of these factors and how they relate to results in previous studies on emotion expression in music performance.

3.1. Heel-to-toe IOI

Results show that there was a significant main effect of emotion for heel-to-toe IOI for the right foot, $F(1.45, 21.746) = 4.275$, $p = .038$, but not for the left foot. There was not significant main effect for factor ground. This suggests that subjects used different heel-to-toe IOI of the right foot for each emotional intention, and that their choices were independent from the particular ground (see Figures 3 and 4)).

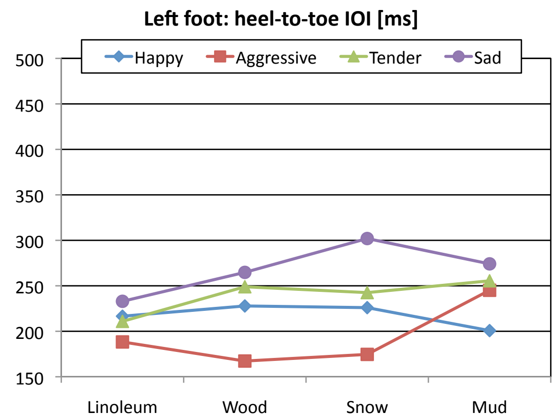

Figure 3: *Left foot mean heel-to-toe Inter-Onset-Interval [ms] for the four grounds, across all subjects, and for each emotion.*

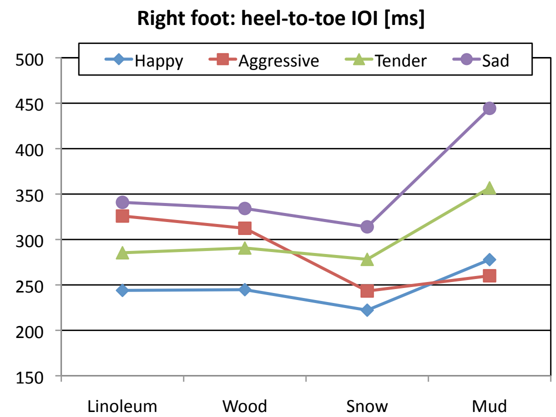

Figure 4: *Right foot mean heel-to-toe Inter-Onset-Interval [ms] for the four grounds, across all subjects, and for each emotion.*

3.2. Heel-to-heel IOI

The results show that there was a significant main effect of emotion, $F(1.361, 20.419) = 6.734$, $p = .011$, but not for factor ground. Also for this parameter, results suggest that subjects used different heel-to-heel IOI for different emotions, and that their choices were independent from the particular ground. Nevertheless, by looking to the mean values, it emerges that subjects had a tendency to change their behavior when the footstep sound changed (see Figure 5). In particular it seems that subjects had a tendency to walk slower, when the footstep sound was that of a muddy ground, and faster, when the footstep sound was that of a iced snow, independently from the emotion.

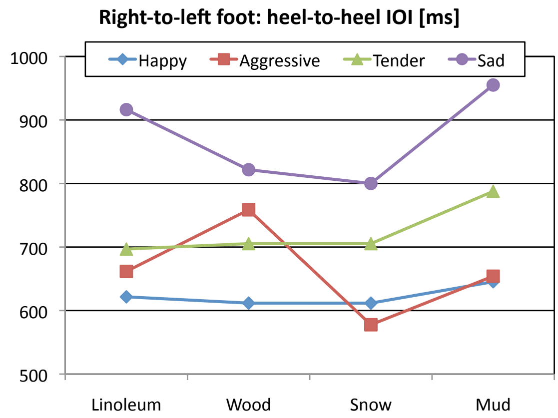

Figure 5: *Mean heel-to-heel Inter-Onset-Interval [ms], between right and left foot, for the four grounds, across all subjects, and for each emotion.*

3.3. Discussion

In general it has been observed the same tendency as in music performance, sad walking was slower than tender and happy walking. Aggressive walking had a more varied speed, and this could reflect previous results in music performance where tempo was not an important parameter for the communication of anger [6]. Results show that walkers used a more active walking style (faster pace) when the sound of the walking surface was characterized by an higher spectral centroid (e.g. iced snow), and a less active style (slower pace) when the spectral centroid was low (e.g. muddy ground). Harder texture sounds lead to more aggressive walking patterns while softer ones to more tender and sad walking styles. It can be noticed that the average value of heel-to-toe IOI for the right foot was larger than the corresponding one for the left foot (see 3 and 4), and that it had a trend similar to that of heet-to-heel IOI. This could suggest that subjects control the walking speed with the right foot.

The preliminary results reported above reflect the answers given by the subjects at the end of the experimental session. Subjects were asked the following final question: ”Do you think there is a relationship between the sound produced by the shoes and the way you were walking during the experiment?”, nine subjects answers *Yes*, six *No*, and one subject *I don't know*. To the follow-up question ”What did influence you most?”, ten subjects answered that they were mostly influenced by the emotion they were asked to express; two subjects found they were most influenced by the sound textures; two subjects were influenced by the test settings, the type of shoes, and the cables attached to them; one subject was more influenced by the instructions he was given; one subject was influenced by the dynamic of the steps.

4. CONCLUSIONS

Even if not statistically significant, it has been found that walking patterns can be influenced by the sound of the ground. In particular there are sounds that make people walk faster or slower independently from the emotional intention of the person. These results could be taken into account when designing the sonification of footstep sounds in virtual reality environments, such as new interactive floors where the sound feedback of footstep sounds can influence the behavior of users, or in rehabilitation and therapy applications when the control of the walking style of a client is a desired goal. For example it could be that subjects can be induced to walk with a faster or slower pace depending on the sound feedback: walking speed is often slower in persons with stroke and it could be modulated using sound as an alternative for example to methods using visual feedback [14].

The experiment was indeed conducted in an unnatural setting, and the nature of walking was influenced by the presence of cables connecting the shoes to the Arduino board. This has certainly introduced a bias in the data collected. This problem will probably be solved with future wireless versions of the shoes.

5. ACKNOWLEDGEMENTS

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