From Shape to Sound: sonification of two dimensional curves by reenaction of biological movements

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Abstract. In this study, we propose a method to synthesize sonic metaphors of two dimensional curves based on the mental representation of friction sound produced by the interaction between the pencil and the paper when somebody is drawing or writing. The relevance of this approach is firstly presented. Secondly, synthesized friction sounds that enable the investigation of the relevance of kinematics in the perception of a gesture underlying a sound are described. In the third part, a biological law linking the curvature of a shape to the velocity of the gesture which has drawn the shape is calibrated from the auditory point of view. This law enables generation of synthesized friction sounds coherent with human gestures.

Keywords: Sonification - Gesture - Drawings - 2/3-power law - Scraping / Friction sounds - Sound Perception

1 Introduction

The possibility to convey information with sounds has been largely investigated the last thirty years and is now commonly called sonification. This field of research aims at transmitting information by sounds either instead of or in addition to a visual display. A common example is the Geiger-Müller counter which produces clicks depending on the quantity of ionizing radiation. The temporal aspect of sounds is particularly interesting to convey dynamic information which could not have been displayed on a screen or with less accuracy.

Pioneering ideas within the domain of sonification were developed by Gaver who adapted Gibson's ecological theory of visual perception to auditory perception [5] to create sounds from perceptual invariants providing relevant informations about an action. Since then, many studies dealing with applications within

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a large number of fields, such as sport training, industrial processes, medicine have been proposed to convey useful information with sound.

This study is included in a larger research project which explores the possibilities to create sound metaphors in the context of different applications[3]. One of these applications is the rehabilitation of dysgraphic children[4] with the use of sounds to guide them to recover the right handwriting gesture. To achieve this goal, we first need to understand how a gesture could be perceptually linked to a sound, and which sound attributes can be used to inform of the dynamical characteristics of the gestures.

In this article, we aimed at proposing a synthesis tool to sonify drawings and more generally two-dimensional shapes. We hereby considered a sonification strategy based on the evocation of the underlying human gestures that might have produced the shapes. In other terms, we aimed at sonifying a drawing by virtually re-enacting a natural gesture of a human that drawn the shape. We considered sounds naturally generated by the interaction between a pencil and a rough surface during the drawing process, i.e. friction sounds. To support our approach, we investigated the relationship between a sound and the evoked gesture and whether a sound can inform of the drawn shape. We therefore conducted experiments to highlight the relevance of the velocity profile as a perceptual attribute of sound that convey information on the underlying gesture and on the drawn shape.

The article is organized as follows. The relationship between a drawn shape and the generated friction sound is firstly studied. We designed a listening test based on a shape/sound association task aiming at examining the subjects ability to recover the correct drawn shape from the sound only. Then, we investigated the influence of the velocity profile on the perceived gesture and shape. For that, a simple synthesis model of friction sounds was used to control this parameter independently from the other ones that are present in a natural gesture (such as velocity, pressure, pencil orientation...). In a third part, the possibility to re-generate a *human* velocity profile of a gesture from the geometrical characteristics of a shape is investigated by a listening test that consisted in calibrating a biological law linking the curvature of a shape to the kinematics of a gesture. Based on this results, a sonification process of shapes is proposed.

2 Shape Discrimination from Friction Sounds

To our knowledge, the relationship between the sound and the drawn shape was not formally investigated in the literature from a perceptual point of view. We therefore designed an experimental protocol aiming at better understand this relationship.

When somebody is drawing, the sounds produced by the friction between the pencil lead and the paper are linked to the gesture behind the drawing. In this

[3] `http://metason.cnrs-mrs.fr/`

[4] Dysgraphy is a motor problem which consequences are difficulties with graphic gestures and to write.

study we examine whether these sounds convey information about the shape which is being drawn.

Stimuli were obtained from recordings of friction sounds produced during a drawing process. A person was asked to draw six predefined shapes (Circle, Ellipse, Loops, Lemniscate, Line, Arches) on a graphic tablet. The velocity profiles of the writer's gestures were also recorded during this process.

To evaluate the possibility to reveal a shape from the friction sounds, a listening test was then set up where subjects were asked to associate one of the recorded sounds to one of the drawn shapes [7]. From the six shapes recorded on the writer, two corpuses of four shapes (two shapes were common between corpuses) were defined; one with very distinct shapes and one with more similar shape, see Figure 1. For each corpus, the subjects were asked to univocally associate one friction sound (among the four available) to one shape.

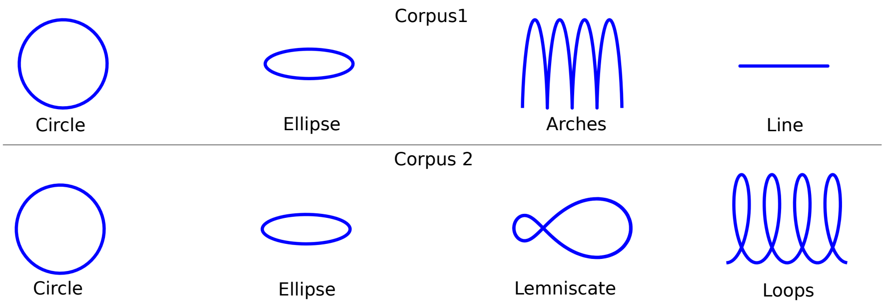

Fig. 1. The two corpuses of four shapes of the association tests

The results of the test show that, except for the *Loops*, each sound was associated with the correct shape with a success rate above random level[5].

In the case of the first corpus, every sounds were properly associated to the shape. The rates of success were: Circle: 98.75% – Ellipse: 81.25% – Arches: 80% – Line: 87.5%.

In the case of the second corpus, confusions appear between the *Ellipse* and the *Loops*, and only the *Loops* were not recognized above chance. The rates of success were: Circle: 97.22% – Ellipse: 41.67% – Lemniscate: 68.06% – Loops: 29.17%.

Although some confusions occurred between shapes of the second corpus, we obtained relatively high success rates. These data showed that sounds produced during the drawing contain accurate information about the drawn shape. To determine the acoustical characteristics that convey this information, we further investigated the relevance of the velocity profile that is one of the important parameter of the motions dynamics.

[5] The random level is defined at 25% sound to shape association rate.

3 Perceptual Relevance of the Velocity Profile

To focus on the influence of the velocity profile, we used a synthesis model which gives the possibility to synthesize friction sounds from the velocity profiles previously recorded on the writer (section 2) by fixing the other parameters (such as pressure, pencil orientation) as constant. We also assumed that the nature of the rubbed surface was identical. A same shape/sound association test as the previous one was conducted with synthetic friction sounds to investigate the perceptual information provided by the velocity profile only. In the following sections, the synthesis model of friction sound is firstly presented and then results of the listening test are discussed.

3.1 A physically based model of friction sounds

Friction sounds have been largely studied and have been the subject of a wide number of applications in different domains of physics. Here we present a simple and common model of friction sounds based on a phenomenological approach of the physical source. This model was firstly presented by Gaver in [4] and improved by Van den Doel in [8].

When a pencil is rubbing a rough surface, the produced sound could be modeled as successive impacts of the pencil lead on the asperities of the surface. With a source-resonator model, it is possible to create friction sounds by reading a noise wavetable with a velocity linked to the velocity of the gesture and filtered by a resonant filter bank adjusted to model the characteristics of the object which is rubbed, see Figure 2. The noise wavetable represents the profile of the surface which is rubbed. Resonant filter banks simulate the resonances of the rubbed object and are characterized by a set of frequency and bandwidth values. Previous studies proposed some mapping strategies allowing for a control of these synthesis parameters based on perceptual attributes (such as the perceived material or size) [1, 2].

3.2 Test and Results

The previous synthesis model allowed us to generate synthetic sounds from a given velocity profile and to accurately investigate whether this parameter is a relevant characteristic of sound perception. We used the velocity profiles previously collected on the graphic tablet and we designed a mapping between these profiles and the cutoff frequency of the lowpass filter. The same listening test as the one presented in section 2 was carried out. Results showed that the shapes of the first corpus (distinct shapes) were properly associated with the sounds with high success rates. The shapes of the second corpus (similar shapes) were associated with lower success rates than for the first corpus, but always above chance level.

In addition, results showed a lack of significant differences between the two experiments (analysis conducted with the type of sounds as factor: recorded vs synthetic sounds). These results revealed that sounds computed from the

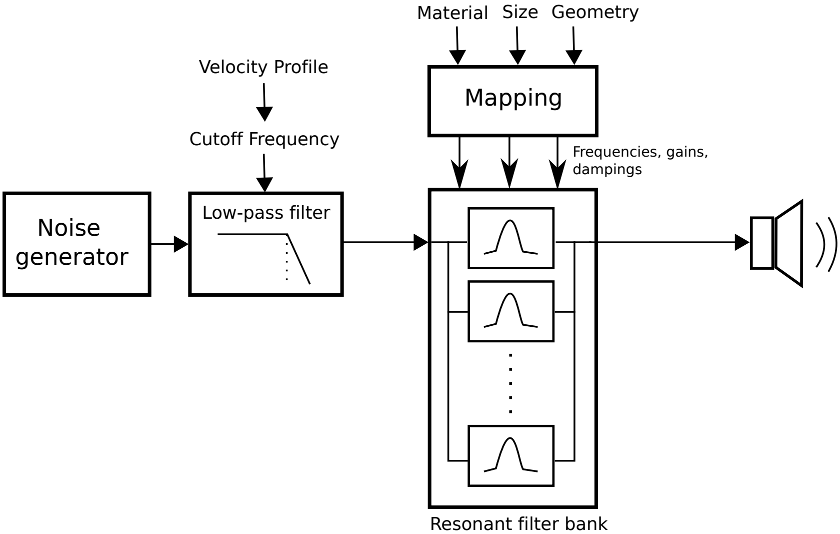

Fig. 2. Physically based friction model

velocity profiles provided as much useful information for shape recognition as the recorded ones. This means that the velocity profile contains the information needed on a shape.

4 Sonification Strategy of Human Drawing

The previous sections highlighted that a mental representation of a shape can be elicited from the sound produced when this shape is drawn and that the velocity profile is a relevant feature of the gesture to convey information on this drawn shape.

In this section we propose a sonification strategy of a drawn trace by recovering the human gesture that produced the trace. We want to create a sound from a given shape using the previous friction sound synthesis model, and the velocity profile as a control parameter. For that purpose, the velocity profile is estimated with respect to the geometrical characteristics of the shape.

4.1 A biological law of motion for the drawing gestures: the 2/3-power law

To regenerate a velocity profile from a given shape, we referred to a biological law which linked the radius of curvature R_c of a shape to the tangential velocity v_t of the gesture which drew it. In [6], Viviani highlighted this relation called the 2/3-power law which expressed the covariations of these two variables with the following formula:

$$v_t(s) = KR_c(s)^{1-\beta} \qquad (1)$$

with $\beta = 2/3$, K is assumed to be constant.

The relevance of this law with respect to the motor competences such as drawing and more generally in many natural movements has been largely studied [6, 10].

This law has also been highlighted in perceptual processes. In the case of visual perception, a study revealed that the perception of the velocity of a point moving along a curved shape should be modulated by such a power law so that the velocity of the point is perceived as constant when the exponent is equal to 2/3 [9]. It means that the notion of perceived constant velocity is not a associated to a physical constant velocity, but to a velocity which respect a specific biological constraint, the 2/3-power law.

4.2 Calibration of the 2/3-power law in the auditory modality

In [7], the relevance of this law was investigated from the auditory perception point of view by a calibration test of the exponent β of the equation 1. For that, we used the previous synthesis model of friction sound. The velocity profile was computed by using the 2/3-power law with a fixed mean velocity K, and with a curvature profile which corresponds to a pseudo-random shape (cf. Figure 3) to avoid preferences on specific known shapes. Each subject did 6 trials and a pseudo-random shape was generated at each one. Subjects listened to the corresponding friction sound and were asked to modify the sound (by acting on the β value) until they could imagine that a human has produced this sound by drawing. The initial value of β was randomized at each trial and the shape was not shown to subjects so that they could focus on the sound only.

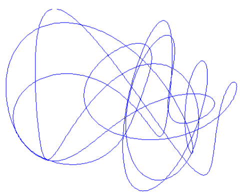

Fig. 3. Example of pseudo-random shape.

We found that the mean value of the exponent was $\beta = 0.64$ ($SD = 0.08$), which means that the most realistic velocity profile which characterizing a human gesture from an auditory point of view follows the 2/3-power law.

This results allowed us to validate the use of the 2/3-power law to generate a velocity profile from a given shape. The obtained velocity profile can further be used to synthesize a sound underlying a mental representation of the gesture.

5 Sonification Tool

The three previous sections gave perceptual results and technical expertise to create a sonification tool of two dimensional curves based on the auditory perception of friction sounds produced by human gestures.

This tool aims at giving a mean to create a sound perceptually coherent with a given shape[6]. The input of this tool could be a scanned shape as well as a shape recorded with a graphic tablet. The Figure 4 sums up the sonification process.

1. The user has to choose a start point on the shape and the direction of the movement
2. From the input shape, the curvature is computed from the coordinates $(x(s), y(s))$ of each point of the shape
3. A velocity profile is created from the curvature with the 2/3-power law
4. The mean velocity of the gesture can be controlled with the coefficient K of the 2/3-power law. The velocity profile controls a friction sound synthesis model and generates a sound coherent with the given shape. The sound could also be played coherently with a displayed movie where the shape is synchronously drawn with the friction sound

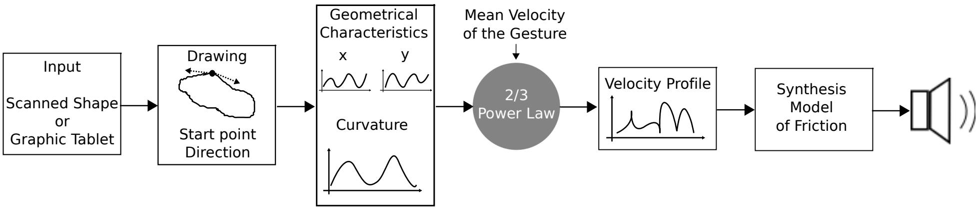

Fig. 4. Complete sonification process

6 Conclusions and perspectives

In this article we proposed a sonification strategy of shapes that could be applied to any set of two dimensional data which could be expressed as a couple of continuous functions. This sonification process, based on the mental representation of a biological gesture underlying a friction sound, transforms the curvature of a shape into a velocity profile which is further used to synthesize realistic friction sounds evoking a gesture coherent with the drawn shape.

This preliminary study also brought up many perspectives. First concerning the possibility to apply the obtained velocity profile to new sound textures other

[6] An example of sonification is available on the following website : `http://www.lma.cnrs-mrs.fr/~kronland/ShapeSoundCmmr`

than friction noise. For instance, if we modulate the pitch of a sound by the velocity profile of a gesture, will this transformation also be relevant for sonifying a shape? More generally, can we use this transformation to create sonic metaphors of a human gesture or drawn shape with abstract sound textures such as wind for example?

Another perspective triggered by this study is the possibility to use the sonification process proposed here for a visual display of a moving spot-light to investigate the multimodal integration of auditory and visual information in the perception of movement dynamics. Viviani highlighted that the 2/3-power law defined a perceived constant velocity in the visual domain. In the auditory domain, we clearly pay attention to *variations* in the sound. It would therefore be interesting to study whether the visual illusion of constant velocity is present when a sound is presented together with the visual display that follows the 2/3-power law.

It should be noted that this work could also be applied to the development interfaces to assist visually impaired. It indeed gives a new way to evoke shapes with sounds.

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