Timbre Perception of Changes in Musical Instrument Geometry using Physical Modeling Techniques

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Introduction

The perception of timber is complex (Krumhansl 1989). Investigations concerning the relation between physical properties of sounds and their cognitive counterparts have been done mostly using the statistical method of a Multidimensional Scaling Technique (MDS) (for an overview see Bader 2002). Here musical sounds are presented to subjects in pairs of all possible combinations. Listeners are asked to rate the similarity of the two sounds of each pair on an interval scale. The MDS then computes an n-dimensional space trying to fit the distances of the sounds onto the spacial dimensions. This creates a room, where the spacial directions are cognitive or perceptional dimensions, orthogonal one to each other. These dimensions need to be compared then to physical parameters present in the sounds. The most cited work here may be Grey (1977). He compared musical instrument sounds and found, that they are judged according to three dimensions:(1) their brightness which physically is a spectral centroid calculated by the formula $c = \frac{\sum_n f(n)A(n)}{\sum_n A(n)}$. with frequencies f and their amplitudes A summed over all n frequencies found in the spectrum of the sound; (2) fluctuations in the quasi-steady-state of the sound; (3) inharmonic components in the initial transient of the sound.

In the literature, often artificial sounds were presented (see i.e. deBrujin 1978). Here, parameters of sounds (frequencies, amplitudes, correlations, fluctuations ect.) were compared to the perceived similarities. Although this is of great interest, in the present study the focus was rather on the comparison **'Instrument geometry - timbre perception'** than on 'Spectral components - timbre perception'. In a previous study to the present work (Bader 2007), the MDS technique was used with sounds built by Physical Modeling (PM) techniques. Of course the spectral components of PM sounds can and will be compared to the cognitive dimensions, too, still for musicians and instrument builders the connection between a change of the instrument geometry directly to the perceived timbre change is the interesting parameter.

Musical instrument model and geometrical changes

Basic model

The whole geometry Finite-Difference model of the violin was used described in [3] which is based on the guitar model described in [2]. We have no space here to get into the details of the model. Still, the standard model uses plate thicknesses of 3mm for the top and back plate and the ribs. The neck has standard dimensions. The model is coupled to the air inside the violin and each violin part is integrated with respect to a virtual microphone positioned 50 cm in front of the parts to simulate radiation. A hard attack was programmed for the violin string / bow system, which was also modelled with a Finite-Difference technique by changing the bowing pressure and the bowing velocity that stable values are reached after 10 ms. So here the initial transient is kept as fast as possible and physically realistic, as - different from the guitarist - the violinist has endless possibilities to perform an initial transient. So to keep concentrating on the steady state and still having a realistic sound a very fast transient was chosen. Then the quasi-steady state of the system is continued for one second so that sounds were produced which could then be used in the MDS test and played to subjects which then judged similarities between these sounds. This was also done for the guitar model although again we do not have space here to show results here. The model was run on a server system with eight parallel processors (Intel Xeon) of 3 GHz with an internal 16 GB RAM.

Method and Geometry changes

The geometry was changed in a linear way. The thicknesses of the plates were increased from 1mm up to 3mm in steps of .25mm so nine sounds were computed. We present here the results for the changes of the violin top plate although very interesting perceptions happened with the other parts, too (changing back plate, ribs, rims, blocks ect.). The test was done by 7 subjects listening closely to the sounds. As they also had to judge the maximum dissimilarity and the sounds differed only a bit one from another, all sounds were played to them in advance to give the listeners a general idea of what will happen. None of the subjects were told about the origin of the sounds, the aim of the study or any other detail of the investigation. In a discussion afterwards between the listeners, many agreed about individual judgements and a stable inter-subject perception of the sounds was obvious. The stress as a statistical measure of the MDS for the fit of the judgements to the spatial embedding was $s_{3D} = 0.19981$ for the three-dimensional and $s_{2D} = 0.29457$ for the two-dimensional embedding. As the stress was still getting better for the 3D, the third dimension was used here, too, which could be justified by the results of reasonable perceptional representation also within this third dimension.

Results

Figure 1 shows the results for the changing violin top plate thickness for three cognitive or perceptual dimensions found by the MDS experiment. The 3D image shows three projection of the perceptual dimensions on the surfaces of the 3D cube. The most interesting one is the projection of dim 1 - dim 2, the bottom of the figure.

As the physical parameter is changing linearly it makes sense to connect the different top plate thickness sounds from 1mm to 3mm. We could expect listeners to 'correctly' perceive this order of sounds so that in one dimension the sounds would be lined up in a row, one after the other.

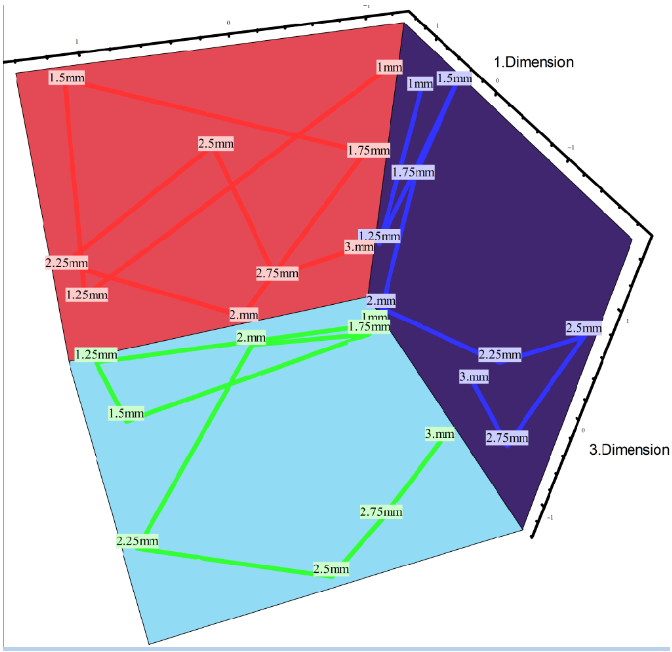

Abbildung 1: Perceptional space of sounds radiated from a violin top plate with changing top plate thickness from 1mm to 3mm (connected in this order). The sounds are shows projected to the walls of the 3D space to compare dim 1 to dim 2 (bottom), dim 1 to dim 3 (right) and dim 2 to dim 3 (back). The results discussed here can be seen on the bottom of the plot.

Dimension 1 shows a clear threshold between the 2mm and 2.25mm sounds. All sounds from 1mm to 2mm are in the back, the sounds from 2.25mm to 3mm are in the front. This makes sense as a violin top plate is seldom thinner that 2.25mm and so the sounds for thinner plates are no longer realistic violin top plate sounds. Here a categorial perception takes place, where listeners all of a sudden judge according to a learned schemata of violin sounds. Indeed one can perceive subjectively that from 2.25mm on the sounds are much more realistic violin top plate sounds. In the discussion after the experiment the subjects were not aware of any threshold of this kind. Remember, that the sounds were presented in random pairs and so a threshold perception is be very difficult within this experimental design. So it is interesting to see that the subjects, only judging similarities, did have this schemata in their minds without noticing them intellectually.

Above this threshold, in dim 2 the sounds 2.25mm, 2.5mm, 2.75mm and 3mm are all in a row. This is a second prove for the schemata perception as a detailed analysis of the spectral components of these sounds did not show any match of any ordering (linear or non-linear increase of decrease) of these sounds according to a spectral parameter. So for this section of the MDS plot, also dim 2 is a schematic one. Listeners seem to have learned how violin plates with changing thicknesses sound and now find this feature in the sounds presented here.

The second half of dim 1 and dim 2 for the sounds of 1mm to 2mm show a completely different behaviour. As discussion this in detail is beyond the scope of this paper we only can mention here, that this is not a random perception but follows different strategies which can be associated with spectral parameters.

Discussion

The changing thickness of violin top plates are correctly recognized by listeners only within a reasonable range of thickness. Here a schemata perception is taking place. This is even more astonishing as the linear change of the violin top plate thickness do not correspond to any linear change in any spectral component but to rather complicated spectral changes. Beyond a threshold, different perceptional strategies are used to judge sounds. In following papers a more detailed description of the perception of this and other geometrical changes will be discussed.

Literatur

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