Characterisation of Musical Sounds by Means of Psychoacoustical Methods

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Introduction

The analysis of the acoustic properties of musical instruments is quite similar to the way noise investigations are done, both have the aim to reach decisions. It can concern a competition, a placing of order, a purchase decision or the evaluation of a technological change. Usually decisions are not taken by experts, therefore, easy to use single-value-results which can easily be compared, will be appreciated.

The sound of a musical instrument causes a sensation which can basically be desribed by pitch and tone quality. The pitch produced by almost every instrument can be measured quite simply with common tuning device. From the pitch values of all single tones of the instrument, an averaged pitch quality result as well as the standard deviation of the pitch can be determined as two important single-value-results. For the evaluation of sound quality procedures are known which get single-value-results, e.g. [1], [2]. All of the common methods work without musicians, because of the large influence they have on the generated sound. Instruments are measured using an artificial excitation (transmission curve measurement, tapping-device, blower). But the real sound of an instrument is neither created by an artificial excitation nor does it consist only of single tones, but of a complex melodic and harmonic structure, shaped by the player. The investigations described in this contribution will help to clarify whether and in which degree the sound of short music pieces can be evaluated using available tools of the psychoacoustical analysis.

Instruments and melody recording

In our lab, sound analysis related to musical instruments is basically done in two steps: First the sound is recorded on DAT, then it is analysed with various kinds of psychoacoustical tools. On stringed and plucked instruments, the transmission function and on wind instruments the impedance on the mouthpiece are measured. The following instruments with different designs and produced by various manufacturers were included in this investigation:

- 10 steel string guitars, two melody recordings
- 10 classical guitars, reference guitars of the IfM, one melody recording
- 5 lutes + 1 reference guitar, one melody recording
- 2 citterns, one melody recording
- 5 bandonions, two melody recordings
- 1 violin with four different bridges, one melody recording

These four bridges included the original bridge and two copies in different materials, namely aluminium and PVC. The third copy is a blank “one eye”.

The music pieces were selected by the musicians involved under the following conditions: The length should be between 20 and 30 s and the piece should characterize the instrument as completely as possible. During fast testing the musician should use it in a typical way. The instruments were recorded in the unechoic room of the IfM. For a microphone an artifical head was used. Player and artificial head were positioned face to face in a 1m distance. The artificial head was adjusted to the height of a sitting person.

Evaluation

Using the audio workstation CF90 from CORTEX with its special implemented algorithm the mean values of the psychoacustical properties loudness (in sone), sharpness (in dezi acum), roughness (in centi Asper) and fluctuation strength (in centi Vacil) were calculated for every music piece. In Table 1, part of the results are presented.

First of all we want to regard the results of the violin. The different bridges are quite large changes on the instrument. Nevertheless the differences are relatively small. Nonetheless, some conclusions can be derived, which correspond very well to the subjective perceptions: 1. The original bridge is obviously the loudest and the one made from aluminium is the softest. 2. For PVC and aluminium bridge, the sharpness clearly decreases compared to the original bridge. The differentiation between PVC and aluminium bridge is not very clear. Some test persons tend to feel the aluminium bar as less sharp. 3. The slight differentiation regarding the roughness does not reflect clearly in hearing tests.

The data were analyzed now on the basis of the following criteria: 1. Which are the substantial sources of the individual parameters in the music pieces? At this point, the mean values were no longer regarded, but the process of the pieces. 2. Do correlations between the music pieces exist, i.e. do the differences the instruments or the pieces? 3. Do connections exist between psychoacoustic parameters and the results of the frequency curve analysis of the plucked instruments?

Fluctuations arise due to the temporal sequence of tones, the rhythm of the piece. In smaller amount, they also appear in slowly decaying chords due to overlapping of the single chord tones. Correlations between the music pieces do not exist.
Roughness arises like fluctuations due to the temporal change of the notes and due to the rhythm of the piece. Furthermore do noise, like the whistling when sliding the fingers over the strings, cause considerable roughness. Finally, long sustained chords also influence roughness. Correlations between the music pieces do not exist.
Obviously, the parameter roughness and fluctuation strength are dominated by the music piece. Thus, they are not suitable for the evaluation of the instruments with music pieces.

The parameters of **loudness** and **sharpness** vary with the sequence of time because of the change in rhythm and melody. But both parameters loudness and sharpness are strongly influenced by the sound quality of the instruments too. In the case of bandonions we found clear correlations between the music pieces for sharpness and loudness. From this follows, both parameters are definitely dominiated by the sound quality of the instruments and not by the music piece, even though the mean values of the compositions are shifted in each case. This strong correlation cannot be found investigating guitars. In the case of sharpness, we assume that the rather small amount of higher frequency tone components of the guitar sound might mainly be the reason.

The results of the frequency curve analyses of guitars show that the total transmission level varies only very little while greater differences are found in lower frequency ranges, comparing guitars of the same design.

Instr.	MS	N/sone	S / da	R / cA	F / cV
WG 1	1	15,7	7,5	22	83
WG 2	1	14,5	8,1	19	97
WG 3	1	13,0	7,7	20	80
WG 4	1	14,2	7,5	18	86
WG 5	1	12,2	7,3	18	86
WG 6	1	10,7	7,7	20	87
WG 7	1	13,2	8,3	18	79
WG 8	1	12,8	8,2	19	93
WG 9	1	11,7	7,5	17	67
WG 10	1	10,7	8,0	20	72
WG 1	2	11,0	7,5	14	59
WG 2	2	8,5	7,9	15	62
WG 3	2	8,6	7,2	12	61
WG 4	2	10,2	7,5	13	63
WG 5	2	9,8	7,6	14	64
WG 6	2	8,2	7,9	8	59
WG 7	2	8,6	7,4	15	63
WG 8	2	9,0	8,2	16	62
WG 9	2	7,6	6,8	11	57
WG 10	2	8,6	7,5	12	61
Band. 1	1	17,4	11,6	57	346
Band. 2	1	19,8	11,4	48	324
Band. 3	1	19,9	11,9	60	306
Band. 4	1	17,5	11,2	54	325
Band. 5	1	12,8	10,7	44	359
Band. 1	2	19,5	12,2	31	119
Band. 2	2	23,3	12,1	25	132
Band. 3	2	22,7	12,4	26	106
Band. 4	2	20,8	11,8	25	113
Band. 5	2	12,0	11,1	36	110
PVC	bridg	16,1	14,8	9	48
Einauge	bridg	16,1	16,1	8	54
Orig.	bridg	18,6	16,6	7	52
Alu	bridg	15,2	15,6	9	56

Table 1: psycho-acoustical data of the instruments averaged over the music pieces

From these results the conclusion can be drawn, that the traditional psychoacoustical parameters offer a starting point for an adequate differentiation of musical instruments of the same type in melody recording. However, they are insufficient for musical instruments.

In the frequency curve analysis we work with two stable characteristics in the lower and middle frequency range: The transmission at about 1 kHz supplies a good parameter for the clarity of the sound of the instruments. The transmission under 400 Hz, in particular below 200 Hz, describes the sound volume or the bass range of the instruments. VALENZUELA [3] created the parameter openness as a result of her sound and hearing analyses, which also considers the range at about 1 kHz. TERHARDT [4] gives a description of the sound volume impression: It rises with decreasing frequency and increasing level. The accomplished analyses always produced the specific loudnesses N ' of the signals. From these, we calculated an openness-value with a simplified algorithm given in [3]. A Parameter for the sound volume was determined by summation of the specific loudnesses starting from 400 Hz downward with the weighting function presented in equation 1.

$$g_{Vol}(z) = 30\exp(-z / Bark) \qquad \textbf{equation 1}$$

Instr.	N/sone	S / da	Volumen	Offenh.
Laute 1	5,4	6,8	2,7	1,5
Laute 2	5,6	6,6	3,1	1,5
Laute 3	5,3	6,7	2,9	1,5
Laute 4	5,7	6,8	2,9	1,7
Laute 5	4,9	7,0	2	1,5
Git. 3	5,5	6,6	4,9	1,4

Table 2: Extended psychoacoustical Data – lute examples

Table 2 represents loudness, sharpness, volumes and openness for the lute. To the five lutes a classical guitar was added. It can be seen that the guitar by loudness and sharpness alone cannot be separated from the lutes, although the difference is clearly audible. Also the differentiation between the lutes is better under the inclusion of the new parameters. Furthermore, it is shown that with guitars openness correlates well with the clarity won from the frequency curves.

Summary

The investigations presented were to determine whether the four traditional psychoacoustical properties, which as is stressed again and again in respective literature were developed for technical noises, can properly descibe the sound quality of musical instruments in melody recording. Fluctuation strength and roughness proved to be unsuitable. Loudness and sharpness produce usable results, but only through the addition of two more parameters can the sound of different instruments be more adequately classified. Openness, one of the new features, is already well defined. The other one, the volume, is intoduced in this contribution. It describes the influence of the lower frequency range on sound perception. A proposition has been made to compute a volume perception value, but it must still be adapted by means of further subjective tests. Other investigations on single tones without any percussive attack, like tones of tongue instruments, showed that fluctuation strength and roughness are useful parameters to describe the sound quality.

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