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MATCHING VIOLINS IN TERMS OF TIMBRAL FEATURES

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In the paper an attempt to match musical instruments in terms of timbral features of their sound is made for a collection of 53 high quality concert violins. The starting point of the analysis is calculation of a set of features based on harmonic analysis, e.g. odd-to-even harmonics amplitudes ratio, intensity of the first and higher harmonics etc., and a set of linguistic descriptors of violin timbre related to these features. The semantically disjoint categories of timbre characteristics are considered. The result of the analysis is the allocation of instruments to those semantic categories with the expectation of the discovery of their similarities in individual timbre dimensions. Although evident matching did not occur, certain possibilities of uncovering expert preferences have been noticed. The outcome of the research provides supportive cue for the design of a method of inferring preference models from the objective characteristics of musical sounds.

Key words: musical acoustics, timbre descriptors, semantic retrieval, violin sound.

1. Introduction

For many years musical acoustics has been based on physical measurements of sound radiated from musical instruments. Later psychoacoustics have played supportive role in understanding how humans hear. A huge number of listening tests led to construction of reliable models of human auditory systems. Nowadays with the development of computer systems we expect from machines to resemble the way humans make decisions based on how they interpret musical sound. The efforts are focused on adding knowledge to systems enabling its more "intelligent" processing. Traditionally, information retrieval methods propose a bottom-up approach from acoustical measurements to human-like understanding of musical content where similarity is based on the lowest level analysis (measurements). The reverse, top down process is not mature yet. Hybrid approaches going from the bottom to the top and in the opposite way are foundation of the critical paradigm of "bridging the semantic gap" [1] between low level description and high level semantic interpretation.

The possible procedure of performing such analysis using fuzzy classification methods and rough sets has been proposed by KOSTEK in [5] e.g. to the process of assessment of musical instruments timbre quality. Timbre is one of the main acoustic features of musical instruments existing along, and often strongly correlated with musical scale, dynamics, time and spectrum envelope of the sound as well as sound radiation characteristics [5]. The most used is the ASA definition of timbre (1960): "Timbre is that attribute of auditory sensation in terms of which a listener can judge that two sounds similarly presented and having the same loudness and pitch are dissimilar". Thus, timbre should be regarded also as a subjective quality that is assessed by listeners. Such subjective assessment is usually not crispy and often depends on listeners' individual preferences not possible to be simply correlated with particular sound parameter. In this higher, semantic level timbre gets descriptive notions as bright, dark, clear, soft, nasal etc. Although the relationship of both levels in most cases cannot be crisply defined, a pursuit to create a semantic lexicon of musical timbre may be recently observed.

In this paper we make an attempt to find the relationship between low and high level timbre description of a set of master quality violins. Usually in machine learning methods individual features are aggregated in pursuit to achieve the best classification results, but this procedure veils features' interpretation. In this paper we are going to deal with the separate semantical dimensions and verify if there exists similarity of violins' timbre expressed by related physical parameters. We will not create the lexicon from scratch, as some authors do (cf. [10]), but follow the taxonomy proposed years ago by KWIEK *et al.* and HARAJDA for violins [2, 6]. The results reported here constitute a part of a longer term study the author has devoted to computer audition of violin sound.

The instruments sounds tested belong to the collection of violins contesting during the 10th International Henryk Wieniawski Violinmaking Competition in Poznań (2001) and gathered in AMATI database [8]. The goals of the paper are following:

- to check the distribution of parameters in the individual timbral dimensions with semantic interpretation for a set of violins from AMATI database,
- to confirm or reject the supposition that the instruments ranked by the jury of competition as the best may have similar timbral features,
- to discover timbre preferences of three experts in separate timbral dimensions.

The paper is structured as follows. In Sec. 2 problems related to violin timbre, its semantic descriptors and related physical features are considered. Section 3 presents results of experiments and their discussion, Sec. 4 concludes the paper.

2. Violin timbre, its semantic descriptors and related physical features

KWIEK and HARAJDA proposed some years ago a taxonomy of violin timbre [2, 6] based on the extensive experiments performed by violinists, acousticians and musicologists. As the authors gave only descriptive outlook based on visual inspection of harmonic spectrum, we added quantitative aspect to their taxonomy using parameters from the domain of musical instruments classification, cf. [4]. The formulas for calculating the parameters from amplitudes of harmonics are presented in Table 1.

Table 1. Formulas for calculating timbral parameters.

Tristimulus 1	Tristimulus 3	Brightness	Evenness	Oddness
$T_1 = \dfrac{A_1^2}{\sum_{n=1}^{N} A_n^2}$	$T_3 = \dfrac{\sum_{n=5}^{N} A_n^2}{\sum_{n=1}^{N} A_n^2}$	$B = \dfrac{\sum_{n=1}^{N} n \cdot A_n}{\sum_{n=1}^{N} A_n}$	$\mathrm{Ev} = \dfrac{\sqrt{\sum_{k=1}^{M} A_{2k}^2}}{\sqrt{\sum_{n=1}^{N} A_n^2}}$	$\mathrm{Od} = \dfrac{\sqrt{\sum_{k=2}^{L} A_{2k-1}^2}}{\sqrt{\sum_{n=1}^{N} A_n^2}}$

$M = L = N/2$; i – amplitude of i-th harmonic, N – number of all harmonics.

Below we characterise descriptors used for categories presented in this paper.

Oddness and evenness of harmonics amplitudes

To check if the amplitudes of even or odd harmonics are more intensive the odd-to-even ratio has been introduced: O_Ev = Od/Ev; semantic terms proposed to their descriptions in relation to O_Ev factor value are following:

tense (oboe like) if O_Ev < 1, *suppressed* (clarinet like) if O_Ev > 1, *equalized* if O_Ev = 1.

Intensity of harmonics

The descriptors that are related to the intensity of harmonics amplitudes are following:

deep (strong first and a big number of other harmonics), *full* (strong first and a small number of other harmonics), *flat* (weak first and a big number of other harmonics), *empty* (weak first and a small number of other harmonics).

The suitable parameters expressing the relationship to the amplitude of particular harmonics is Tristimulus 1 (relative contribution of the first harmonic in harmonic spectrum) and the Tristimulus 3 (relative contribution of fifth and higher harmonics in harmonic spectrum).

Centre of gravity of harmonic spectrum

Centre of gravity of the spectrum is responsible for the impression of brightness – one of the best recognized attributes of musical timbre. Two descriptors expressing it have been introduced: *bright* (sharp) and *dark*. According to ŠTĚPÁNEK [10] the boundary between two categories is for the frequency 1200–1400 Hz, however certain pitch-related scaling should be applied due to the pitch dependency in perceiving timbre (cf. e.g. [5]).

There are more different categories used for expressing timbre – their examination deserves further study, we recall here some of them. Trend of harmonics amplitudes gives the sound described (in [2]) as *normal* (6 dB drop in harmonics amplitudes), *strained* ($<$ 6 dB drop in harmonics amplitudes), *light* ($>$ 6 dB drop in harmonics amplitudes), however there are other models of harmonics trend, eg. evaluated by PREIS in [9]. Formant placement and character (*soprano*-*alto* and *sonorous*-*hollow*) is another timbral dimension. Interesting is the concept of LOTTERMOSER [7] who back in fifties analysed the intensity of harmonics from the point of view of perception of musical intervals – consonance or dissonance. This idea has been recalled recently by WRZECIONO in his MSc thesis supervised by the author [11].

3. Experiments and discussion of results

Two experiments have been performed. Both have been carried out on the sounds of violins from AMATI database [8]. Only open string sounds have been analysed.

3.1. Experiment I: analysis of the distribution of timbral features in individual dimensions

The experiment has been conducted for a set of 53 instruments. The goal was to get the insight into the distribution of timbral features values and to verify if the instruments ranked by the jury of competition as the best are comparable in any of timbral dimensions and thus may be characterized by similar semantic descriptors. Figures 1 and 2 present the results of calculating exemplary parameters values for four open strings (O_Ev ratio and Tristimulus 1 vs. Tristimulus 3). The best instruments have been pointed up.

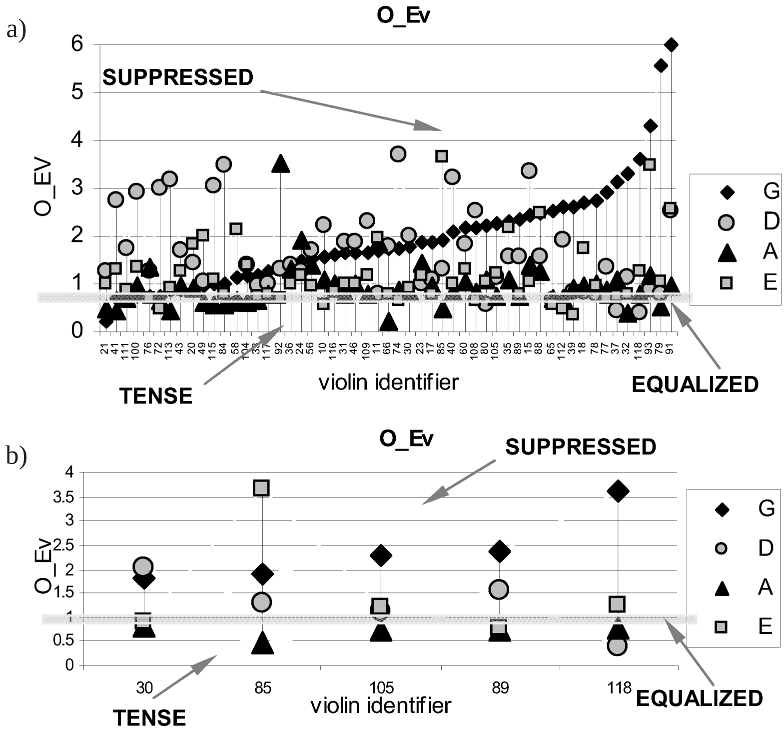

Fig. 1. Odd-to-Even harmonic amplitudes ratio of individual open strings sounds calculated for: a) 53 violins, b) violins ranked as the best in the competition. The features have been ordered according to G-string. Grey line – rough inter-class boundary.

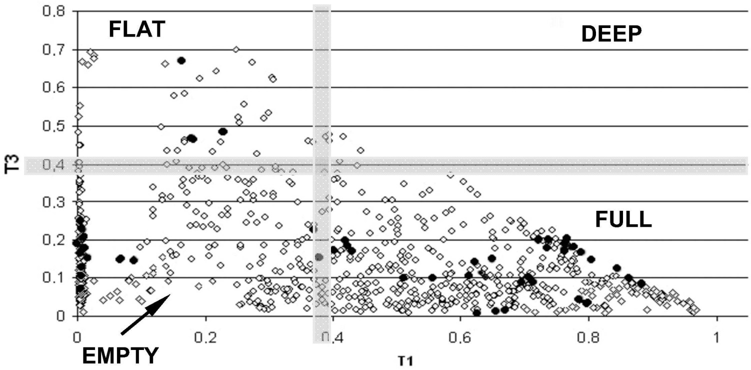

Fig. 2. Intensity of the first versus higher harmonics expressed as Tristimulus 1 (T1) vs. Tristimulus 3 (T3) for individual open strings sounds calculated for 53 violins. The violins ranked by jury as the best are black. Grey thick lines – rough inter-class boundaries.

Discussion of results: The experiments have shown, that on one hand feature values for a set of violins are spanned almost linearly over given range if individual strings are compared (in Fig. 1 this is illustrated for G-string), and on the other that scattering of values for sounds of the individual violin strings are different from instrument to instrument. The boundaries between semantic categories are not expected to be very exact, and have only approximate character. The majority of examined violin sounds are "equalized", i.e. odd and even harmonics are equally intensive. It is interesting to note, that the G-string sound of the numerous instruments might be characterized by the term "suppressed", and this feature is evident for the best instruments. The physical nature of G-string sound is such, that the first harmonic is very weak. It explains the low (almost equal to zero) value of Tristimulus 1 for certain sounds in Fig. 2. That gives the impression of "emptiness" (the best instruments) or "flatness" of the G-string sound. Another observation is that sounds of contemporary concert violins from all over the world are not "deep", according to [2] – i.e. do not have strong first and strong higher harmonics (high values of Tristimulus 1 and Tristimulus 3). Indeed in such a case instruments would sound "squeaky" as some authors say. Certainly the best instruments have "full" timbre.

3.2. Experiment II: comparing timbral features of 13 instruments assessed by 3 experts

Timbre of 13 various quality violins from AMATI database have been assessed by three experts: the violinist (V), the violinmaker (VM) and the musicologist (M) in independent listening test. Figure 3 presents exemplary graphs of centre of gravity of tested instruments (aggregated values for four strings). The feature values in all three graphs are the same as the same instruments have been tested, only the order in which they are presented is different and relies on experts' ranking. To illustrate an estimated profile of expert's preferences, the trend line has been added.

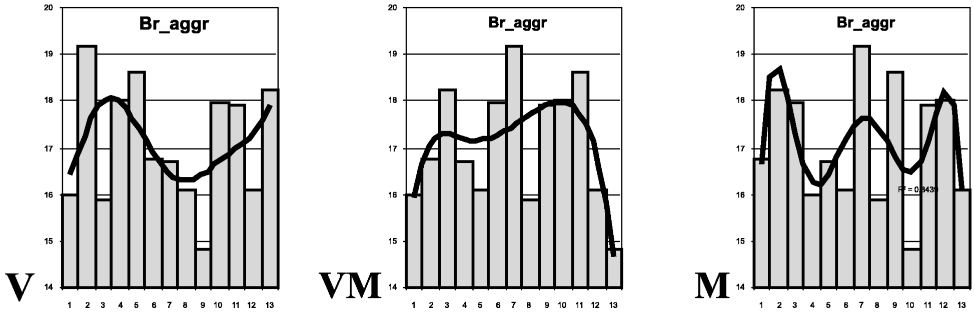

Fig. 3. Three orderings of the values representing centre of harmonic spectrum gravity (aggregated for four strings) of 13 violins ranked by: V – violinist, VM – violinmaker, M – musicologist. Trend line has been added to facilitate semantic description of preferences, calculated as the centre of gravity of the spectrum of individual open strings.

Discussion of results: Brightness is the feature the most recognized for instruments. It is different for each string of the same instrument and the space of brightness of all four strings is different. In Fig. 3 the aggregated values of centre of gravity have been shown. However the curve representing the trend of individual features and the aggregate are similar. They represent preferences of experts that may be expressed by lexical terms, i.e. instruments ranked by expert V as the best are bright, however the same feature is also characteristic for instruments rated low. Evidently dark instruments are preferred by expert VM (as a double-bass admirer he indeed preferred darker timbre). For the third expert M obviously brightness was not an essential feature for qualifying the timbre. For none of experts the trend line has been monotonic – it has not been monotonic for other features either. It means, that fuzzy decision supporting methods have to be used for discovery of listeners' preferences in many timbral dimensions.

4. Conclusions

In the paper an attempt to match musical instruments in terms of timbral features of their sound has been made for a collection of 53 high quality concert violins. Emphasized should be the new aspect of the analysis, i.e. using semantic equivalents for expressing timbre subjective impression, that may help uncovering listener preferences. The experiments did not prove evident match of the best instruments in terms of these individual features, however, using fuzzy methods, probably it will be possible to create the categories (both quantitative and semantic) based on the multidimensional feature space. To complete this task further experiments using more diverse sounds from AMATI collection and introducing new timbral categories will be carried out.

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