SOUND DIRECTIVITY SPECTRAL SPACES OF VIOLINS

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Abstract

A method for measuring and evaluating sound directivity radiation is described. A sixteen-channel recording system is used for measuring sound directivity of musical instruments. Microphones for measurement are placed in an anechoic room on a horizontal plane in a circle surrounding the measured instrument. The plane is vertically shifted into five positions, and additional microphones positions in the lowest and highest planes are added, providing a measuring net of 98 positions on a closed cylinder. Analytical and statistical methods used for the construction of sound directivity spectral space from 98 recordings are described. An example of spectral space and its representation by signals with main spectral contrasts on the G3 violin tone is given.

INTRODUCTION

Every musical instrument, when played by a musician, radiates different amounts of sound energy both in direction and frequency. Directivity of sound radiation of musical instrument steady-state tones was precisely measured and described. The classical approach to sound directivity description in acoustics is to quantify directivity of sound radiation for individual frequencies or in a specific frequency band [1], but it is possible to regard radiated sound in each direction as a complex signal. Generally, it is believed that the shape of the signal's spectral envelope (possibly changing in time) is responsible for sound timbre; thus, spectrum changes induced by direction changes can imply timbre changes for steady-state tone playing. The goal of our long-term project is to describe **directivity dependence of timbre** of some classical musical instruments, and try, alternatively, to describe observed timbres through adequate spectral features.

A developed system for measuring musical instrument directivity sound radiation is described, together with analytical methods used for the spectral characterisation of sounds radiated in different directions. Statistical methods are used to select representative sounds for later subjective evaluation of timbre differences. Another approach to the problem of directional dependence of timbre is described in [2].

METHOD

Sound radiation directivity measurement system

The recording system consists of sixteen Sennhaiser ME 62 microphones, a sixteen-channel amplifier, and a Pentium PC with two ARC88 sound cards (16 bit A/D and D/A, sampling frequency 44.1 kHz). Microphones for measurement are placed in an anechoic room on a horizontal plane in a circle (with a diameter of 3.2 m or 1.6 m respectively) surrounding the measured instrument. The plane is shifted vertically in steps of 0.5 m from the floor into five positions, which are extended by nine additional microphone positions in the lowest and highest planes, providing a measuring net of 98 microphone positions on a closed cylinder (see Figure 1). Individual microphone positions are indicated by three characters: the first two indicate the horizontal plane (A1 – A5, B1, B5), the third informs on microphone position (1 – 9, A, B, C, D, E, F, G). Supporting structure enables later system transfer into any other space. An SPL of recordings is corrected for different distances of microphones from the instrument and for the player's variability in loudness.

Signal analysis and spectral characteristics

Quasi-stationary parts of recorded steady-state tones were defined using the critera of L_{max}–3 dB. Mean amplitude spectra were calculated from these quasi-stationary parts. Further miscellaneous spectral characteristics were calculated, as they emphasise different aspects of signals manifested in a spectrum.

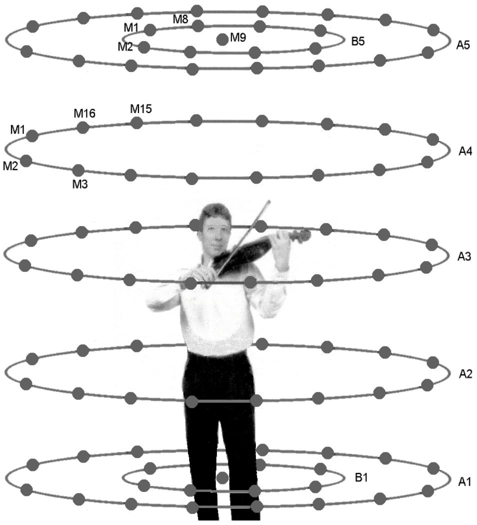

Figure 1. A configuration of microphones and violin position during recordings. Microphone set M1 – M16 positions are denoted from A1 to A5 and B1, B5.

The harmonic spectra (levels in individual harmonics) and Bark spectra (levels in critical bands) were used as spectral characteristics. Levels of harmonics from the fundamental up to harmonics, with a sufficient level considering their audibility, are usually included in the harmonic spectrum. There is no information on non-harmonic components of the signal in the harmonic spectrum. Information weight of every harmonic is considered to be constant and equal to one. Statistical treatment is able to discover possible influences of any harmonic in the spectrum, but common behavior of a group of harmonics prevails over individual harmonic influence. Higher frequencies are over-estimated with respect to perception weights (critical bands), so it is useful to calculate Bark spectra as well. On the contrary, rigid boundaries of critical bands can suppress important local events, which could, for example, be positioned near the band boundary. Some lower critical bands describe non-harmonic components which can influence the tone perception. Consequently, both harmonic and Bark spectra have some advantages and disadvantages.

Statistical evaluation

The square root of the sum of squared level differences in the corresponding harmonic/band was used to calculate the distance between signal pairs [3] in a set of 98 spectra:

$$d_{ij} = \sqrt{\sum_{k=1}^{n}\left(L_{ik} - L_{jk}\right)^{2}} \quad i, j = 1, ..., 98 \qquad (1)$$

where n is the number of harmonics/bands.

The multidimensional scaling method (MDS) can be used for the construction of sound directivity spectral space from the signal distance matrix calculated for any type of spectra. In this study we have used nonmetric MDS procedure and correlation analysis of resulting dimensions and level values in harmonics/bands.

RESULTS AND DISCUSSION

Tones played on a François Gand (1825) violin in an anechoic room were recorded using the method described above. The violinist used *mezzoforte* dynamic, down-bow *detache*, position *naturale*, and *non-vibrato* playing. The player's variability in loudness was detected and corrected.

The following processing results concern the G3 violin tone signals recorded in 98 positions. Harmonic and Bark spectra of all 98 recordings and their distances using formula (1) were calculated. An example of variability of spectral levels with dependence on the recording position are found in Figure 2 for signals from microphones six and twelve in the plane A3 (indicated as A36 and A3C). This variability gives different timbre and loudness in listening these signals.

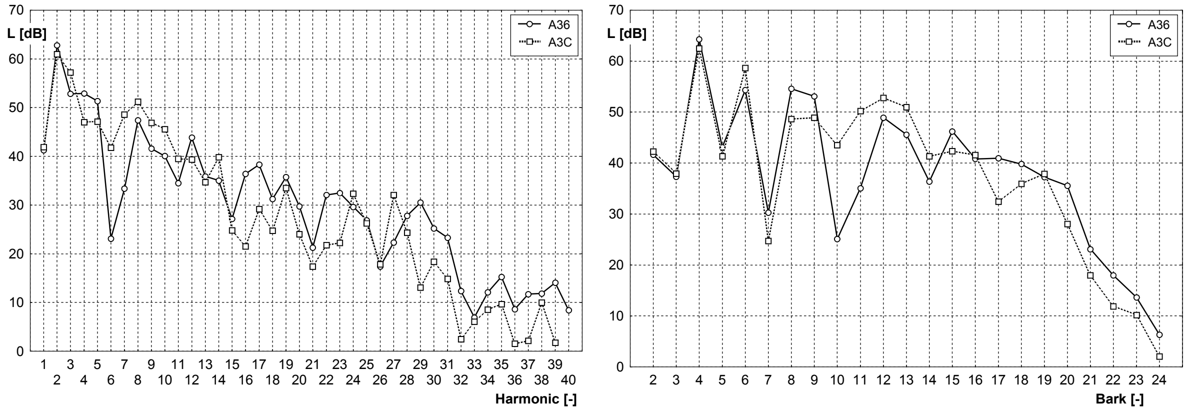

Figure 2. Harmonic and Bark spectra of the G3 violin tone calculated from recordings in position A36 and A3C.

The MDS method was applied both on harmonic and Bark spectra distances. Levels of harmonics from the first harmonic (frequency 196 Hz) up to 40 (7840 Hz) and in Bark bands 2 – 24 were included in the processing. Due to the high number of objects (98 signals) processed we were able to choose a relatively high number of dimensions. Using STATISTICA (StatSoft ®) software we were limited to nine dimensions.

At first we compared both spaces, where the first dimension coordinates have significant correlation and seem nearly identical. The range of signal coordinates in this dimension exceeded the range of other dimensions more than three times, so the first dimension is the most prominent one. Other dimensions with significant correlation are second dimensions, the third 'harmonic' and fourth 'Bark' dimension, and the fourth 'harmonic' and third 'Bark' dimension.

Next, we calculated correlations between dimension coordinates and levels in individual harmonics/bands and focus on the description of results obtained for harmonic spectra. The first dimension had significant correlations in all 40 harmonic levels and is evidently connected to the overall level of the spectrum and thus with signal loudness. Other dimensions had significant correlations with small groups or single harmonic levels, and are undoubtedly connected to sound directivity radiation features. For future subjective directivity evaluation in listening tests we have selected two representative (contrasting) signals in each dimension, which have a large difference in the coordinate of this dimension and small coordinate values in other dimensions. Projections of pairs of sound directivity spectral space dimensions from the first up to the sixth with contrasting signals in each dimension are found in Figure 3.

CONCLUSIONS

A large variability in violin sound radiation measured in 98 directions around the instrument can be perceived as variation in loudness and timbre, and can be recognised in the spectrum. The described method for the construction of sound directivity spectral space is a suitable tool to describe variability sources in spectra and enable selection of representative signals for future listening tests.

ACKNOWLEDGMENT

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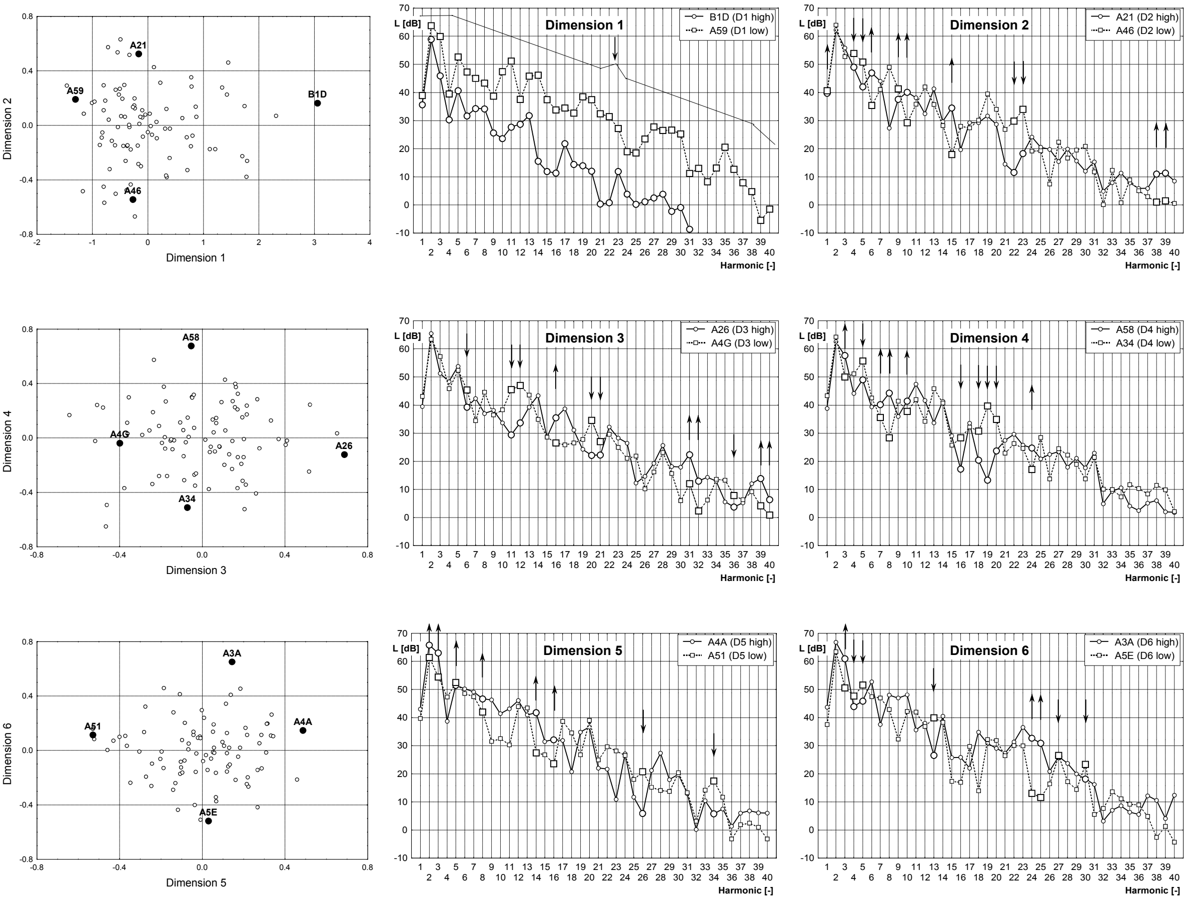

Figure 3. An example of projections of pairs of dimensions from the nine-dimensional sound directivity spectral space, representative contrasting signals in each dimension are highlighted. Harmonic spectra of contrasting signals are displayed; harmonic levels correlated significantly with dimension coordinates are marked by arrows, oriented according to the correlation sign.