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A METHOD OF DETECTING THE C4 VIOLIN MODE IN THE ENERGY SPECTRA OF CHROMATIC SCALES

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This article presents a method of detecting the frequency of the C4 mode of the violin in the energy spectra of chromatic scales. The recordings from the AMATI multimedia database, which includes recorded sounds of violins taking part in the 10-th Henryk Wieniawski International Violin Making Competition in Poznań, are used in the study.

The method is based on the search for the part of the energy spectra of recorded chromatic scales which is common for these spectra. The recordings were made in the near field, separately for each string. The analysis of the spectra was made in a 650 to 796 Hz band, with the 0.5 Hz resolution. All the instruments in the AMATI database were tuned to A4 = 443 Hz. The frequencies of the strings were as follows: the G string: 196.89 Hz, the D string: 295.34 Hz, the A string: 443 Hz, the E string: 664.5 Hz.

Keywords: violin modes, chromatic scales, AMATI, DTFT.

1. Introduction

In multimedia databases, which include recordings of musical instruments, a possibility of instrument identification by characteristic properties of their sound is very important. Frequencies of violin modes are usually used for the description of violin sound. The modes are marked by C1, A0, C2, T1, C3 and C4 [1, 2]. On the base of previous studies [3, 4], a method of searching for violin modes C1, A0, C2, T1 and C3 was developed [5]. This article describes the method for searching the C4 mode.

2. Method

2.1. The main assumptions

The spectrum of chromatic scale includes the frequencies of played scale steps and the violin modes [3–5]. A characteristic property of sounds from chromatic scale is an inaccuracy of intonation which results in a deviation of the actual frequency of the tone from its nominal frequency. On the other hand, the frequencies of violin modes depend on the construction of the instrument and are independent of the violinist. This difference between properties of the violin modes and the chromatic scale steps permits to find the frequencies of violin modes.

The recordings of the chromatic scale were made separately for each string. For that reason, it was possible to search for the common maxima in each spectrum of recordings. Statistical methods were used in this study.

2.2. *The estimating of probability of hitting the right pitch*

Each step of chromatic scale has its nominal frequency, but in the case of violin, the actual frequency of the tone depends on the precision of violinist. A good violinist can play with 10-cent precision [6]. Because of that, the frequency of a scale step played on the violin is a random variable. The properties of this random variable must be estimated, because it is necessary to calculate the probability of the event, that on each string, the same chromatic scale step has the same frequency.

The frequency interval of ± 10 cents around the frequency of a chromatic scale step may be calculated by the following formulas [6]:

$$\begin{aligned} f_1 &= f_s/1.0058, \\ f_2 &= f_s \cdot 1.0058, \end{aligned} \tag{1}$$

where f_1 is the lower frequency of the 20-cent bandwidth, f_2 is the higher frequency of the 20-cent bandwidth, f_s is the frequency of the chromatic scale step.

In this study, a 650–796 Hz bandwidth was used. The calculated frequencies f_1, f_2 and bandwidths are the following:

Table 1. The bandwidths of 10-cent precision of chromatic scale steps (A4 = 443 Hz).

f_s [Hz]	f_1 [Hz]	f_2 [Hz]	bandwidth [Hz]	$\frac{f_s - f_1}{f_s} \cdot 100\%$	$\frac{f_s - f_2}{f_s} \cdot 100\%$
650.00	646.26	653.77	7.51	0.58	–0.58
688.65	684.68	692.64	7.96	0.58	–0.58
729.60	725.40	733.83	8.43	0.58	–0.58
772.98	768.53	777.46	8.93	0.58	–0.58

All of bandwidths in Table 1 are symmetric in relation to f_s frequency. This fact allows us to use the Gaussian distribution to estimate the random variable of hitting the right pitch.

Frequency f_s was taken as an expected value and the half of bandwidth $f_2 - f_1$ as a standard deviation. As a result the following probabilities of hitting the right pitch were obtained:

Table 2. The probabilities of hitting the right pitch.

f_s [Hz]	$\frac{f_2 - f_1}{2}$ [Hz]	Probability
650.00	3.7546	0.6827
688.65	3.9778	0.6827
729.60	4.2144	0.6827
772.98	4.4650	0.6827

Four recordings of a chromatic scale were used in the presented method. These recordings were made separately for each string. The probability of the event of hitting the right pitch on all strings is very important, because if the value of probability is less than 0.5, there will be a possibility to find a deterministic part of all chromatic scales spectra. In this case, the probability can be calculated by the following formula:

$$P_{hrp} = P_g(f_i) \cdot P_d(f_i) \cdot P_a(f_i) \cdot P_e(f_i), \tag{2}$$

where P_{hrp} is the probability of hitting the right pitch of all strings, f_i is the frequency of chromatic scale step, P_g is the probability of hitting the right pitch for G string, P_d is the probability of hitting the right pitch for D string, P_a is the probability of hitting the right pitch for A string, P_e is the probability of hitting the right pitch for E string.

The value of P_{hrp} for 650–796 Hz bandwidth is 0.21723. Then, there is a possibility to find the deterministic common part of energy spectra for all strings.

2.3. *The method of detecting the C4 mode*

The frequency of C4 mode is in the bandwidth from about 700 Hz to 800 Hz [1, 2]. Therefore the searching for C4 mode should be made in this frequency range. Because each string may produce sounds within a range from 650 Hz to 795.56 Hz [7], the analysis of recordings of chromatic scales were made in this bandwidth with 0.5 Hz resolution. The spectra were calculated by DTFT [8], because this transform makes possible to calculate a sample of spectra for prescribed frequency. The recordings from the near field were used in the study. The violins from AMATI [9, 10] database was tuned to A4 = 443 Hz.

The algorithm of detecting the C4 mode is following:

1. Calculate DTFT of recording of chromatic scale in 650–796 Hz bandwidth, separately for each string.
2. Calculate the samples of energy spectra.
3. Normalize the energy spectra of chromatic scales according to maximum value of energy. This operation is made for each string separately.
4. Create the multiplication table (M table), the elements of which are calculated according to the following formula:

$$M[k] = E_{g\,\mathrm{norm}}[k] \cdot E_{d\,\mathrm{norm}}[k] \cdot E_{a\,\mathrm{norm}}[k] \cdot E_{e\,\mathrm{norm}}[k], \tag{3}$$

where k is the index of energy spectra sample, $E_{g\,\mathrm{norm}}[k]$, $E_{d\,\mathrm{norm}}[k]$, $E_{a\,\mathrm{norm}}[k]$, $E_{e\,\mathrm{norm}}[k]$ are k-th samples of normalized energy spectra of G string (g), D string (d), A string (a) and E string (e).

5. The frequency, for which the $M[k]$ has the largest value, is marked as the C4 violin mode.

This algorithm was implemented in C++ language using Qt library for user interface. The programme was compiled by gcc and tested on Linux platform openSuSE 10.2.

3. Results of calculation

In a given bandwidth, only one pronounced maximum was observed, but some violins have a maximum of $M[k]$ over 796 Hz. The examples of M table are presented below.

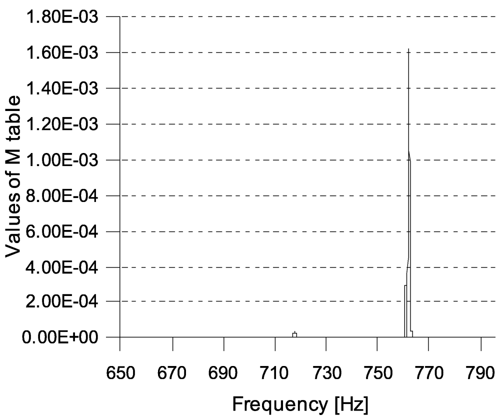

Fig. 1. The diagram of M table for violin marked with number 10.

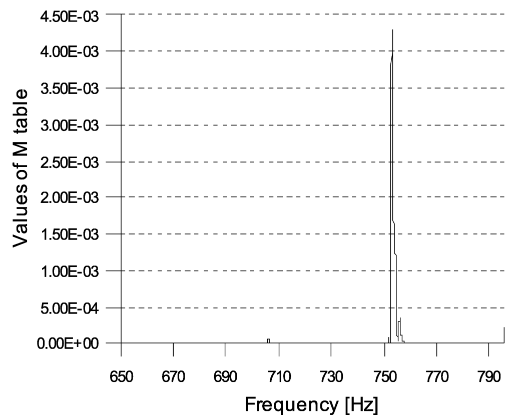

Fig. 2. The diagram of M table for violin marked with number 85.

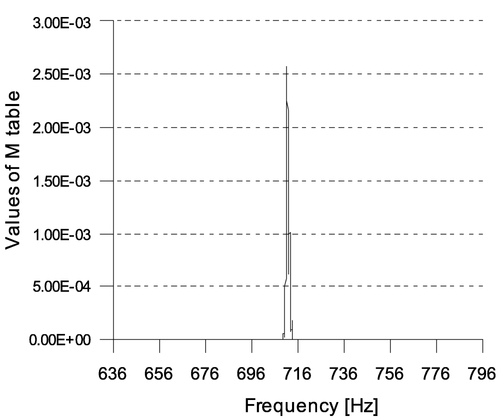

Fig. 3. The diagram of M table for violin marked with number 89.

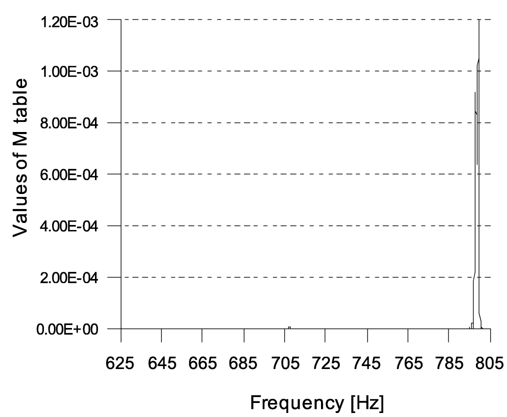

Fig. 4. The diagram of M table for violin marked with number 30.

The frequencies of modes for exemplary violins are given below in Table 3.

Table 3. The detected frequencies of C4 violin mode for exemplary instruments.

Violin number	The C4 Frequency [Hz]	Violin number	The C4 Frequency [Hz]
10	762.0	30	799.5
60	798.5	72	794.5
76	705.5	80	759.5
85	753.0	89	711.5

4. Conclusion

The results from described method are very similar to the results given by other authors [1, 2]. Additionally, this method allows searching for modes with frequencies higher than C4 and such searching has not been conducted before [1, 2]. This method could also be useful in the case of other bowed string instruments because of similar construction. The main advantage of the algorithm described in the paper is the explicitness of the found frequency of mode C4.

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