European Journal of Science and Theology, December 2011, Vol.7, No.4, 103-119

COMPLEX ANALYSIS OF THE BELLS' SOUNDS FROM THE 'SAINT TRINITY' CATHEDRAL FROM ALBA IULIA

Constantin Oancea[1], Constantin Gheorghies[2] and Simona Condurache-Bota[2*]

[1] *Theology Department, Faculty of History, Philosophy and Theology, 'Dunarea de Jos' University, 111 Domneasca Street, 800201 Galati, Romania*
[2] *Physics Department, Faculty of Sciences, 'Dunarea de Jos' University, 111 Domneasca Street, 800201 Galati, Romania*

(Received 25 November 2010, revised 14 April 2011)

Abstract

The analysis of the sounds emitted by the new system of bells from the Saint Trinity Cathedral of Alba Iulia, Romania was performed and compared to a witness sound, by means of complex acoustic analysis programs called Wavanal and Sigview. The study of the partials influence on the amplitude, intensity and, inherently the pitch of the resulting sounds emitted by the bells system is also considered. The change in time of the partials intensity and amplitude during a bells' ringing cycle is studied as well, by comparison with the witness sound. Rather significant differences were noticed between the recorded sound and the witness sound, even though they have the same essential musical characteristics and even though they sound alike to the human ear.

Keywords: sound analysis, partials, church bell, sound spectrum

1. Introduction

For any church, its ringing bells are representative both from the architectonic and aesthetic point of view, along with their sound perception. This is why choosing the right set of bells for a church is an important and delicate task. Details about the proper material, wall thickness, shape, size and number of bells and finally even choosing the right manufacturer have to be studied prior to the acquisition of a ringing bells set.

As known, bells belong to the percussion musical instrument class. A note or a set of notes on a musical scale are assigned to each bell, thus identifying and differentiating between them. This particular assigned note is also used to judge whether a bell is 'in tune' with others in a set of bells (*i. e.* a *chime* [1]). The sound impression of a bell is called *pitch*. More precisely, the pitch represents a

* Corresponding author: sbotacond@yahoo.com, phone: +40 336130 251, fax: +40 236 319 329

subjective sensation in which a listener assigns perceived tones to relative positions on a musical scale based primarily on the vibration frequency [2, 3]. Still, the pitch cannot be measured by means of instruments. In order to differentiate objectively between sounds, one needs to perform complex sound analysis both in the time domain and in the frequency domain. This is where physical methods come along, as they do almost every time when it is either about thorough analysis of religious or art objects or about their cleaning and maintenance [4-6]. In this case, the Acoustics branch of Physics comes and gives the right answers concerning the characteristics of the sounds emitted by the church ringing bells. In its beginning, the main purpose of the acoustic research was the elucidation of the mechanisms by means of which human auditory system can analyze and precisely discriminate between complex sounds [3]. Afterwards, the scientific research in the field developed continuously, reaching nowadays the performance of building complex computer-assisted programs, which are capable of recording and/or importing sounds with certain file formats, to analyze them, both in the as-recorded time domain, but also in the frequency domain, following the Fourier transform of the original recording.

Thus, taking into consideration that each person has its specific sensitivity to sounds, in order to properly characterize the ringing performances of a certain church bells system, one has to use specialized computer analysis programs. This way one can check the harmonic content and the entire spectra of the sounds emitted by the bells system, either in order to make the proper choice when ordering a bells system for a certain halidom or in order to verify if they sound as specified by the manufacturer.

Wavanal and Sigview are such competitive sound analysis programs and it were used for the study of the sounds emitted from the new set of ringing bells from the ‘Saint Trinity’ Cathedral of Alba Iulia, Romania.

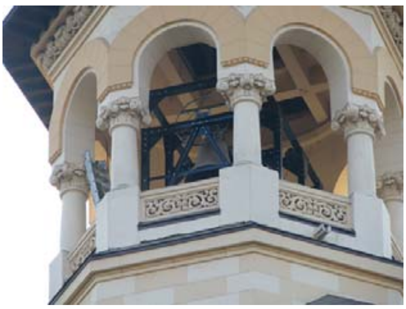
This Cathedral (see Figure 1) is a symbol of the union between all the Romanians and of the Romanian Christianity. It is located in the heart of Transylvania, in a place which holds memories from the most solemn moments in the history of the Romanians. It was built between 1921 and 1922, on the occasion of King’s Ferdinand and Queen’s Mary coronation, an event which took place on October, the 15th, 1922. The inauguration of ‘Saint Trinity’ Cathedral in Alba Iulia was called Transylvania’s intabulation in Romania. Enshrining the historical act from December, the 1st, 1918, of the Great Union of all Romanians, the Cathedral was also called the Coronation Cathedral.

The original bells from the Cathedral, from which the lightest weighted 400 kg and the heaviest weighted 1500 kg were lowered one by one from the Cathedral’s tower when they became too old and, especially, too damaged, such that they could not be used any more. They are now exhibited at the Orthodox Archdiocese museum from Alba Iulia. In their place, the Orthodox Archdiocese from Alba Iulia ordered a new system made of 3 ringing bells, at a world-famous bell foundry from Austria. The bells were casted-on on June, the 19th, 2008, from an electrolytic copper alloy and from electrolytic antimony, in specific proportions. The optimum casting temperature of the molten metal alloys is

1075 °C. The cooling time of the bells' alloy was about 6 weeks long, depending on the size of the bell to be cast-on.

The 3 bells were built in a RE-FA-LA musical harmony. The diameter and the weight of each of the bells are given in Table 1 [7].

(a)



(b)

(c)

Figure 1. a) 'Saint Trinity' Nation's Reunification Cathedral from Alba Iulia, b) its bells' tour, c) one of its ringing bells.

Table 1. Characteristics of the new ringing bells from 'Saint Trinity' cathedral.

No.	Emitted sound	Diameter, d (cm)	Weight, m (kg)
1.	RE D	136	1530
2.	FA F	115	890
3.	LA A	91	450

The new three bells system of the 'Saint Trinity' Cathedral from Alba Iulia is put in motion by an engine which is computer-driven. A GPS antenna allows the synchronization of bells' ringing according to the movement of the geostationary satellites. This complex bells ringing system can be ordered to start by means of either a remote control or a mobile phone, the latter being done by dialling a special code, known only by the priests from the Cathedral.

This paper presents the results of a thorough acoustical analysis of the sounds emitted by the new bells system. This analysis was done in order to check the musical harmony of the bells, specified by the manufacturers, as compared with a standard/witness sound having the same basic musical characteristics (*i.e.* the RE - FA - LA harmony), taken from the literature [7]. The performances and the usefulness of the acoustics was analysed by means of computer programs Wavanal [8] and Sigview [9]. This study represents a part from a big project concerning the comparative analysis of the sounds emitted by the bells from 25 church and monasteries all over Romania. Thus, a relationship between the precise acoustical parameters obtained by specific complex acoustic analysis programs and the musical impression left by the bells from saint places will be established.

2. Theoretical notions

The sound emitted from a bell is composed by the sum of its specific partials and from residual noise. A partial is a certain frequency from the sound spectrum, given by a certain mode of bell vibration. Except from the percussion class, all the other musical instruments have partials at integer multiples of the fundamental frequency emitted from each instrument. In the case of bells, which belong to the percussion class of instruments, the partials represent fractional multiples of the fundamental frequency [2]. The sound spectrum of a bell, i.e. the amplitude or intensity of sound versus frequency, is composed of peaks corresponding to the partials, with background given by the bell's noise.

The partials with frequencies bigger than that of the fundamental component of a certain complex sound are known as overtones or upper partials and they have specific names, in increasing order of their frequencies: *hum, prime, tierce, quint, nominal* and *superquint* [1-3, 10-14].

It has to be reminded here that the sound or acoustic intensity (I) is defined as the sound power per unit area, expressed in W/m^2. The sound intensity level, L_I is defined as [1]:

$$L_I = 20 \cdot \ell og_{10} \frac{I}{I_0} \quad (1)$$

with I_0 being the reference intensity. L_I is expressed in dB (deciBells). Concerning the reference intensity, its value is taken as 10^{-12} W/m^2 in most cases. Still, in the case of bells, the reference intensity is that of the partial from the sound spectrum with frequency closest to that corresponding to the LA 4 note (440 Hz), whose intensity level is, thus, equal to zero [1, 2].

3. Experimental

A sound file recording of 78 seconds long emitted by the ringing bells system from 'Saint Trinity' cathedral of Alba Iulia, Romania was analyzed [7]. Wavanal and Sigview software, were used for the analysis of file, which had .mp3 extension.

The Wavanal program is capable to perform the Fourier transform of the original sound recording and to display the resulting sound spectrum, where the characteristic partials are also identified. This program is capable of building up a sound from its individual partials. This noise-free sound is called the *witness sound* or *the sound control*. By comparing it with the original sound, the noise component can be identified and its contribution to the sound perception can be inferred [2, 10-14].

In the case of the present study, the witness sound was taken from the literature [7], as having the same musical characteristics RE-FA-LA as the sound recorded from the cathedral's ringing bells. The witness sound recording had 92 seconds duration.

More precisely, the algorithm for choosing the witness sound for comparative analysis with the original recording from the Cathedral is as follows:

- The sound is downloaded from http://www.clopote.ro/armonii.html [7] and then it is listened through the Wavanal program;
- Corresponding to the weight and size of each of the three bells from the cathedral, the scale of each bell and the harmony of the bell system are identified, according to the stipulations made by the manufacturer [7];
- From a certain archive given by the manufacturer [7], the witness sound corresponding to the bells' harmony from the cathedral is taken, and then it is analyzed by means of the Wavanal program.

The Wavanal program allows for precise analysis of the bells' sounds in terms of frequency identification of each partial, of the exact amplitude and intensity of each partial, as they are contributing to sound perception. This analysis was performed both for the recorded and for the witness sound. The corresponding sound spectra allowed for clear comparison and identification of differences between the two sounds [1].

The Sigview program allows to plot the waveform of each sound recording, to perform and to display the Fast Fourier Transform (FFT) of the sound recordings and to plot two and three-dimensional correlations between magnitudes, which are important for sound analysis, such as amplitude, intensity, frequency and time. The 3D representation of amplitude versus intensity and frequency, respectively, by means of the Sigview program can be numerically-fitted with a formula which clearly states the intercorrelation between these three magnitudes [13].

Within the analysis presented in this paper, done by means of the Wavanal and Sigview software, the acoustic intensity is called 'amplitude', which can be understood as an arbitrary unity-expressed measure of the sound recording done by means of a certain recording device. Also, the 'intensity' refers to the sound intensity level, expressed in decibels.

4. Results and discussion

4.1. Wavanal analysis of bells sounds from the 'Saint Trinity' cathedral from Alba Iulia

Figures 2 and 3 exhibit the plots of the Fourier transform of the recorded sound and that of the witness sound, respectively, as resulting from the Wavanal program. Tables 2 and 3 present the acoustical and musical characteristics of all the identified peaks in the spectra from Figures 2 and 3, done through Wavanal. Thus, the results of the analysis of the sounds emitted by the new bells system from the 'Saint Trinity' cathedral from Alba Iulia are presented in Table 2, while Table 3 presents the same type of parameters as obtained by the analysis of the witness sound. The frequency and the amplitude of each peak are given in columns 2 and 3. The sound intensity level is calculated in dB for each partial in column 4. The main upper partials are identified in column 5. Column 6 contains the notes names, the indication of the octave to which it belong (in brackets), followed by a number lying in the range -50 to +50, which indicates the number of cents away from the exact note. The numbers given in column 7 of both Tables 2 and 3 represents the deviation in cents from the note with 440 Hz frequency (LA 4) [2].

As a reminder, the *cent* is a logarithmic unit of measure used for musical intervals, being given by the interval of pitch between two frequencies υ_1 and υ_2 equal to:

$$1cent = 3986.31 \cdot \ell og_{10} \frac{\upsilon_2}{\upsilon_1} \qquad (2)$$

Thus, one *semitone* has 100 cents (*i.e.* a cent represents one hundredth of a semitone) and one *octave* (with a frequency ratio of 2:1 from one end to the other) is equal to 1200 cents. The interval of one cent is much too small to be heard between successive notes, but its multiples are useful when one wants to measure extremely small musical intervals.

Columns 8 and 9 from Tables 2 and 3 present the results of the computation of the ratios υ/υ_0 and υ/υ_{nom}, respectively, of each peak's frequency to that of the smallest frequency (υ_0 = 222 Hz for the recorded sound and υ_0 = 79 Hz for the witness sound, respectively) and to that of the nominal ($\upsilon_{nom} = 879$ Hz for the recorded sound and $\upsilon_{nom} = 1765$ Hz for the witness sound, respectively).

The last four rows of Tables 2 and 3 contain data concerning the range of each magnitude, their average value and their standard deviation, denoted as STDEV and defined as:

$$STDEV = \sqrt{\frac{\sum_{k=1}^{N}\left(x_k - \overline{x}\right)^2}{N}} \tag{3}$$

This magnitude expresses the degree of spread of a set $\{x_k\}$ of N data around their average value $\overline{x}$.

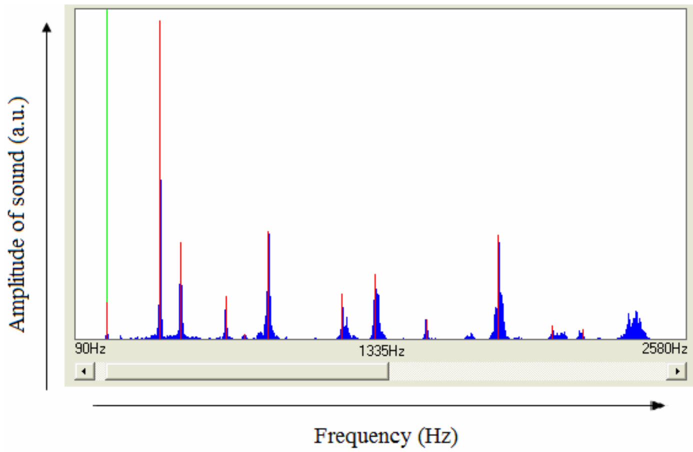


Figure. 2 Fourier transform of the recorded bells' sound as resulting from the Wavanal program.

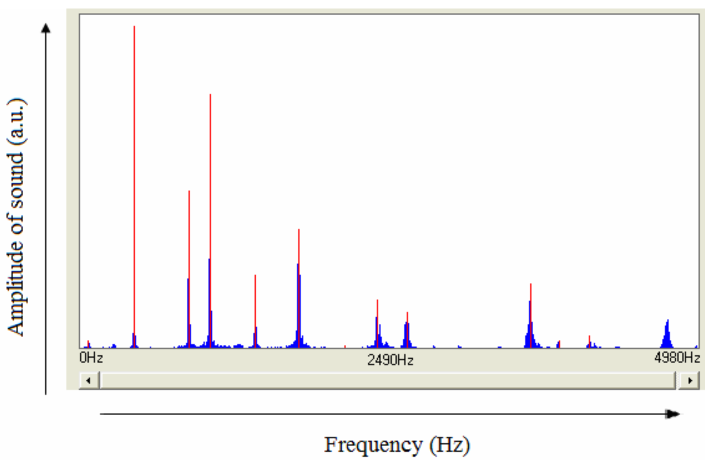


Figure. 3 Fourier transform of the witness sound, as resulting from the Wavanal program.

Table 2. Characteristics of the cathedral's bells' recorded sound, extracted from the Wavanal program.

No.	Freq. (Hz)	Ampl. (a. u.)	Sound intensity level (dB)	Partial	Note	Cents	Ratio to lowest freq.	Ratio to nominal
1.	222	1.167	- 18.35	HUM	A(0)+15	- 2382	1	0.25
2.	438	9.649	0.00	PRIME	A(1)-7	- 1206	1.97	0.50
3.	520.5	2.982	- 10.20	TIERCE	C(2)-9	- 907.1	2.34	0.59
4.	706.5	1.361	- 17.01	QUINT	F(2)+19	- 378.2	3.18	0.80
5.	781	0.1907	- 34.08		G(2)-6	- 204.6	3.52	0.89
6.	879	3.321	- 9.26	NOMINAL	A(2)-1	0	3.96	1.00
7.	1178	1.44	- 16.52		D(3)+4	506.8	5.31	1.34
8.	1315	2.016	- 13.60	SUPERQUINT	E(3) - 5	696.6	5.92	1.50
9.	1522	0.6639	- 23.25		F#(3)+47	949.8	6.86	1.73
10.	1813	3.18	- 9.64	OCT. NOM.	Bb(3)-48	1253	8.17	2.06
11.	2033	0.4717	- 26.22		B(3)+49	1451	9.16	2.31
12.	2155	0.3611	- 28.54		Db(4)-49	1553	9.71	2.45
13.	3559	0.3105	- 29.85		A(4)+18	2421	16.03	4.05
Min.	222	0.1907	- 34.08			- 2382.0	1.00	0.25
Max.	3559	9.6490	0.00			2421.0	16.03	4.05
Average	1317.1	2.0857	- 18.19			288.7	5.93	1.50
STDEV	913.2	2.5309	9.83			1311.7	4.11	1.04

As it can be noticed both from Figures 2 and 3 and from Tables 2 and 3, a number of 13 peaks were identified in the spectrum of the recorded bells' sound from 'Saint Trinity' cathedral from Alba Iulia, with frequencies ranging from 222 Hz till 3559 Hz, while for the witness sound with the same musical characteristics, only 12 peaks were noticed, in the 79÷4094 Hz frequency range.

The diagrams from Figures 4-7 present the dependencies amplitude versus frequency and the intensity versus frequency, respectively, both for the recorded sound and for the witness sound, the names of the partials being also given on each corresponding peak. It can be noticed that in the amplitude versus frequency plots there are several satellite partials whose positions differ at the recorded sound as compared to the witness sound. Their contribution to the whole perception of each sound, *i.e.* to the *pitch*, is not that important for differentiating the two sounds.

Table 3. Characteristics of the witness sound, extracted from the Wavanal program.

No.	Freq. (Hz)	Ampl. (a. u.)	Sound intensity level (dB)	Partial	Note	Cents	Ratio to lowest freq.	Ratio to nominal
1.	79	0.28121	- 31.30		Eb(-1)+26	- 5378	182	0.04
2.	445	10.32332	0.00	HUM	A(1)+19	- 2385.3	5.6325.71	0.25
3.	883	5.08523	- 6.15	PRIME	A(2)+5	- 1199	11.18	0.50
4.	1051.5	8.15408	- 2.05	TIERCE	C(3)+8	- 896.6	13.31	0.60
5.	1415	2.40031	- 12.67	QUINT	F(3)+22	- 382.6	17.91	0.80
6.	1765	3.87182	- 8.52	NOMINAL	A(3)+4	0	22.34	1.00
7.	2137.5	0.15767	- 36.32		C(4)+36	331.5	27.06	1.21
8.	2391	1.59749	- 16.21		D(4)+30	525.5	30.27	1.35
9.	2636.5	1.20627	- 18.65	SUPERQUINT	E(4)+0	694.7	33.37	1.49
10.	3622	2.12351	- 13.74	OCT. NOM.	A(4)+49	1244.5	45.85	2.05
11.	3852	0.30073	- 30.71		B(4)-43	1351.1	48.76	2.18
12.	4094	0.44152	- 27.38		C(5)-38	1456.6	51.82	2.32
Min.	79	0.15767	- 36.32			- 5378.0	1.00	0.04
Max.	4094	10.32332	0.00			1456.6	51.82	2.32
Average	2631.6	2.99526	- 16.37			- 366.5	25.71	1.15
STDEV	1337.6	3.31551	12.03			1344.1	16.32	6.76

Much more striking is another readily noticeable difference: the approximately double values for the frequency of the partials from the witness sound as compared to the partials of the cathedral's bells' sound, even though the human ear perceives them as similar. Thus, the intensity versus frequency diagrams of the two analyzed sounds have similar peak distribution (highs and lows), but at completely different frequencies.

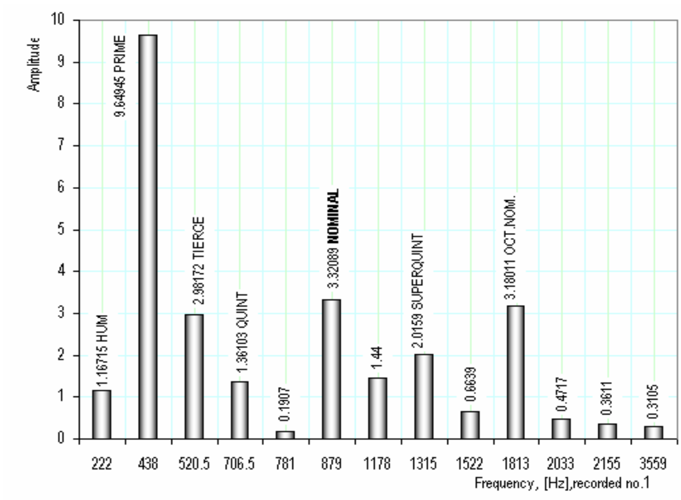


Figure 4. Amplitude dependence on frequency for the recorded sound from the ringing bells.

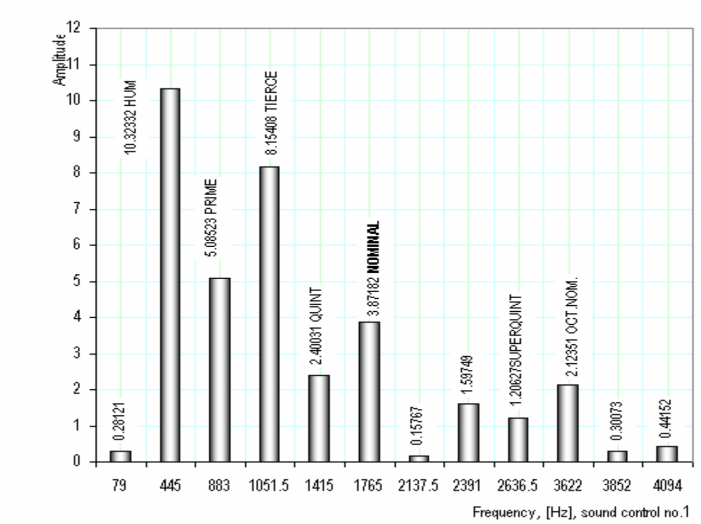


Figure 5. Amplitude dependence on frequency for the witness sound with the same musical harmony as the recorded sound.

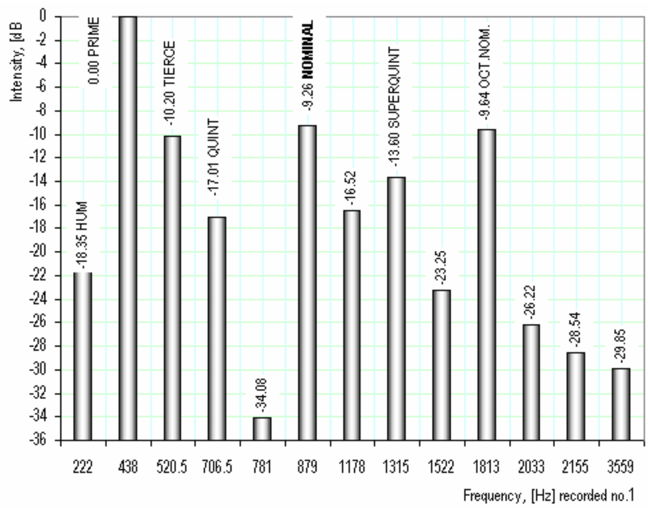


Figure 6. Intensity of sound versus frequency for the recorded bells' sound.

The analysis of the main partials for the compared sounds is made in Figures 8 and 9. In these figures, the superimposed plots of the amplitude of sound versus frequency and of the intensity of sound versus frequency are given only for the main partials of the recorded sound and for the witness sound. In Figure 8, one can notice that there are rather important differences between the amplitudes of the main partials of the two analyzed sounds, especially at low frequencies, while in Figure 9 it can be seen that the differences between the intensities of the partials of the two compared sounds are bigger at high frequencies. The differences between the intensities of the two analyzed sounds are smaller than for the corresponding amplitudes, because the logarithm function attenuates the variations.

The differences between the amplitude versus frequency graphs on one side, and the intensity versus frequency, on the other side are to be expected, since the two magnitudes are defined in different manners and their dependence on the frequencies of sounds are, inherently, different, showing some specific aspects of the analyzed sounds.

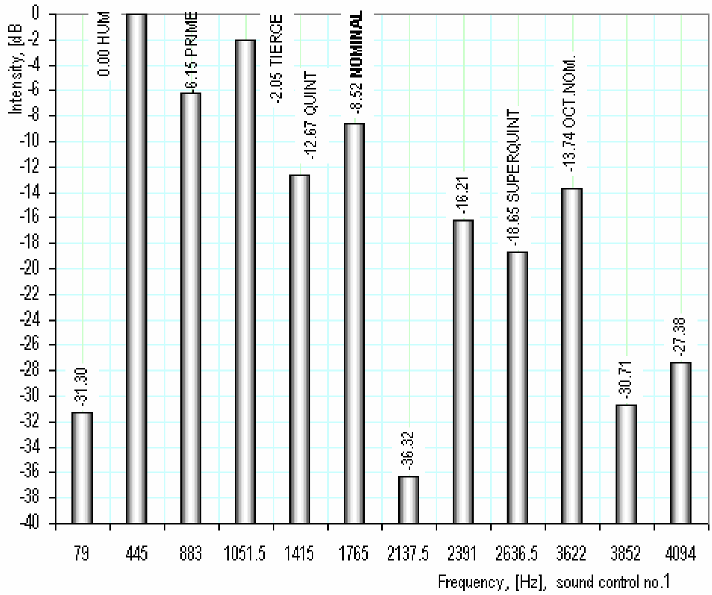


Figure. 7 Intensity of sound versus frequency for the witness sound, having the same musical harmony as the recorded sound.

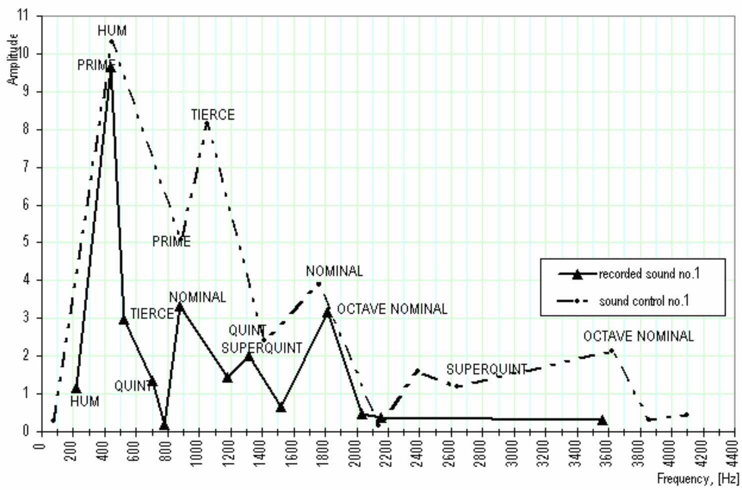


Figure 8. Amplitude of sounds versus frequency plots for the main partials of the two analyzed sounds.

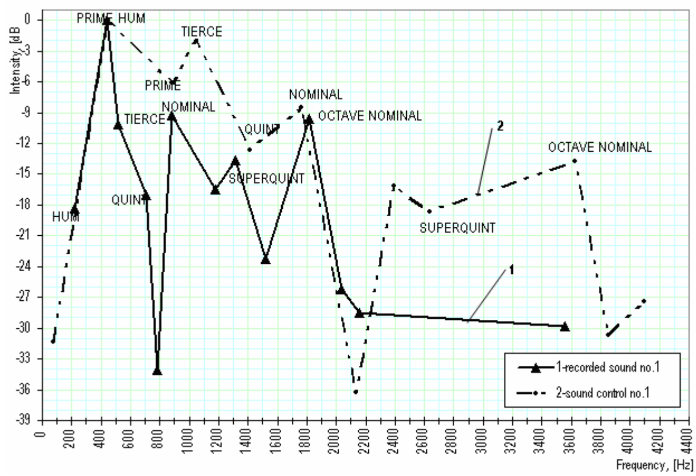


Figure 9. Intensity of sounds versus frequency plots for the main partials of the two analyzed sounds.

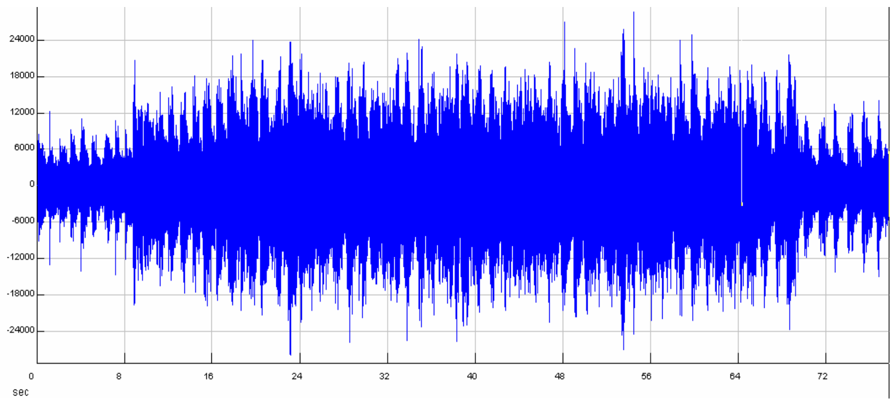


Figure 10. Waveform for the sound emitted by the new bells system from the 'Saint Trinity' cathedral from Alba Iulia.

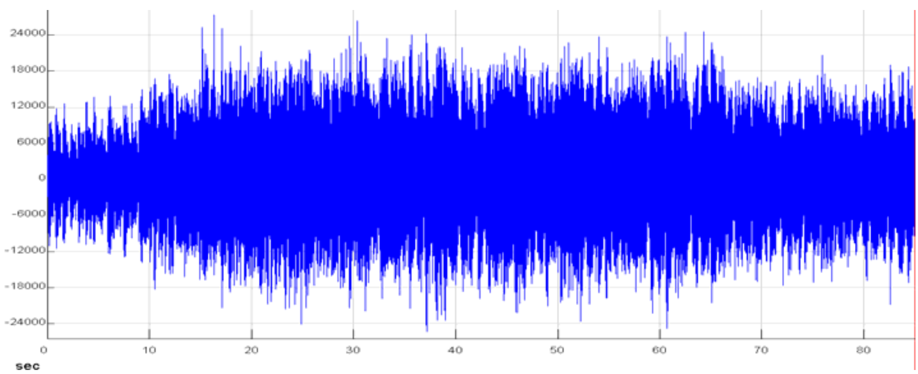


Figure 11. Waveform for the witness sound.

4.2. Sigview analysis of the bells sounds from the 'Saint Trinity' cathedral from Alba Iulia

Figures 10 and 11 present the waveforms of the two analyzed sounds, *i.e.* of the cathedrals' bells' recorded sound and of the witness sound, as plotted by means of the Sigview program. Figures 12 and 13 present the Fast Fourier Transforms (FFT) corresponding to the two sounds, as computed by means of the same program. These FFTs are another type of spectra representation than those obtained with the Wavanal program, in a different frequency range. Thus, the frequencies range between 0 and 1850 Hz for the recorded sound (78 seconds recording time), while for the witness sound, lasting 92 seconds, the FFT in Figure 13 is given in the 0-3700 Hz frequency range (with 92 seconds recording time).

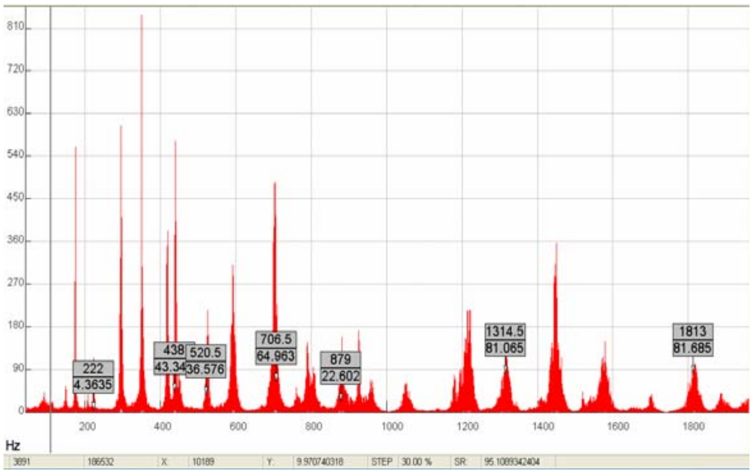


Figure 12. FFT graph in the 0÷1850 Hz range for the bells' sounds from the 'Saint Trinity' cathedral from Alba Iulia.

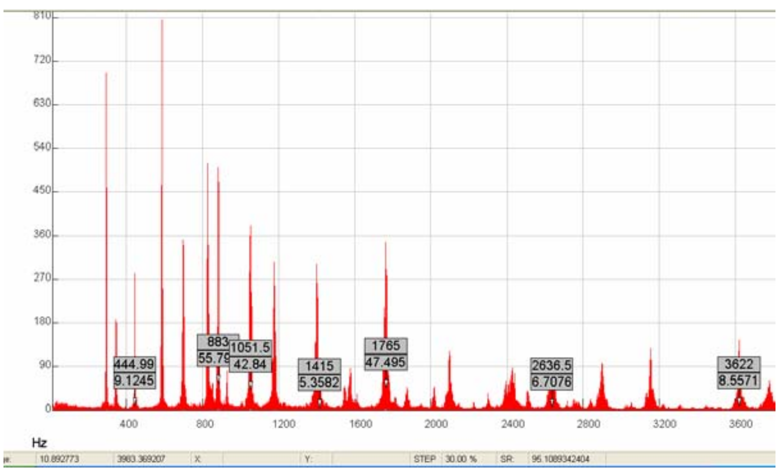


Figure 13. FFT graph in the 0÷3700 Hz frequency range, for the witness sound.

Even though the two analyzed sounds have the same musical harmony, their spectral distributions are different. Thus, the maximum amplitude in the FFT plot is reached at ≈ 350 Hz for the recorded sound, while for the witness sound the maximum amplitude is reached at ≈ 580 Hz. Satellite frequencies are also noticeable in these kinds of plots and their contribution to the entire sound perception it seems that it cannot be neglected, but the human ear cannot perceive their influence.

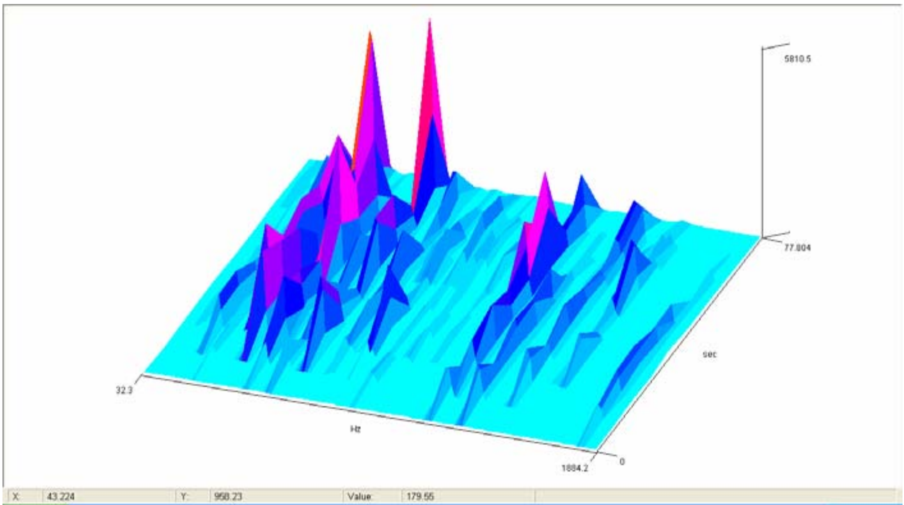


Figure 14. 3D time FFT analysis: x-axis: time (s), y-axis: frequency (Hz), z-axis: amplitude, for the recorded sound.

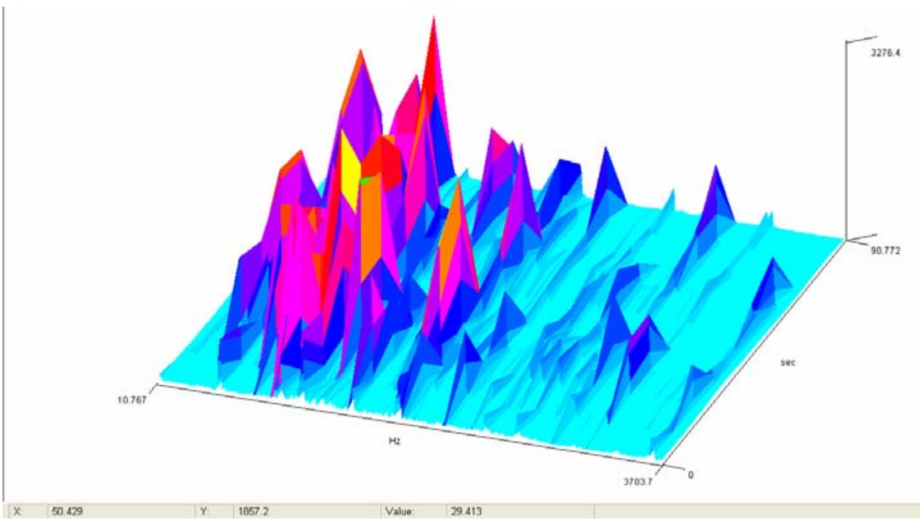


Figure 15. 3D time FFT analysis: x-axis: time (s), y-axis: frequency (Hz), z-axis: amplitude, for the witness sound.

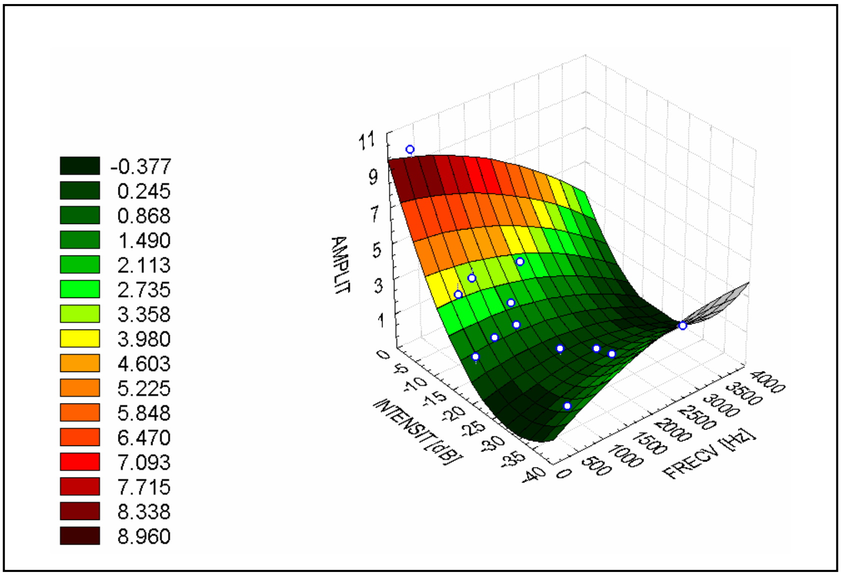


Figure 16. 3D representation of the amplitude (z) versus intensity (y) and frequency (x), for the recorded sound

.

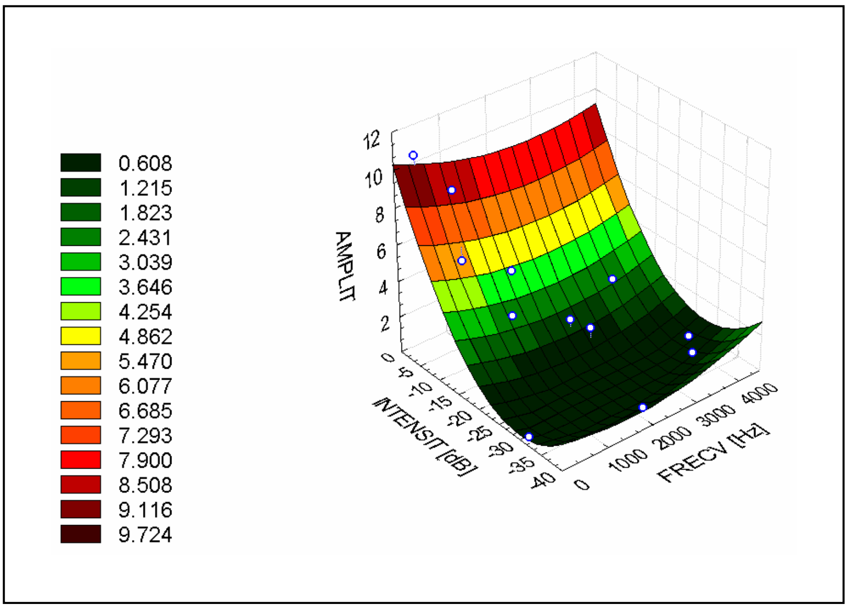


Figure 17. 3D representation of the amplitude (z) versus intensity (y) and frequency (x), for the witness sound.

Figures 14 and 15 present the time evolution of the amplitudes of the partials taken from the Fast-Fourier Transforms given in Figures 12 and 13, versus frequency, for the cathedral's bells' sound and for the witness sound, respectively. These plots are also done by means of the Sigview program. There is a clear higher density of peaks in the 3D plot at low frequency for the witness sound (see Figure 15) as compared to the recorded sound (in Figure 14). This means that the lower frequency partials maintain their amplitude in time for the witness sound, while for the cathedral's bells' sound, the amplitude of the lower frequency partials increase at the end of the recording time.

The final graphs given here are the ones from Figure 16 and 17, representing the reciprocal dependence between the amplitude of sound, the intensity of sound, in dB, and the frequency of the cathedral's bells' sound and of the witness sound, respectively. A formula can be inferred from these 3D plots, that links the amplitude, denoted as the *z* variable, with the intensity of sound, in dB (as the *x* variable) and with the frequency of the partials (the *y* variable).

Thus, for the bells' sound from the 'Saint Trinity' cathedral, the inferred formula is:

$$z = 9.583 + 0.702 \cdot y - 2.478 \cdot 10^{-7} \cdot x^2 + 0.012 \cdot y^2 \quad (4)$$

The corresponding formula for the witness sound, describing the 3D surface from Figure 17 is:

$$z = 10.331 - 0.001 \cdot x + 0.684 \cdot y + 1.961 \cdot 10^{-7} \cdot x^2 + 0.012 \cdot y^2 \quad (5)$$

Thus, if in the previous two formulas one considers z as the effect and x and y as the causes, then the two equations show an almost linear dependence of z with x and y, since the coefficients accompanying x^2 and y^2 in both formulas are small. It can be noticed a better uniformity of the 3D surface in Figure 17 with changing frequency, corresponding to the witness sound as compared to the 3D plot for the cathedral's bells' sound, from Figure 16.

5. Conclusions

The sounds emitted from the 3 ringing bells system from the 'Saint Trinity' cathedral in Alba Iulia were analyzed as compared to a witness sound with the same three notes musical harmony of RE-FA-LA. The analysis was done by using two complex analysis programs called Wavanal and Sigview. The comparative analysis made it possible to identify the similarities and the differences between the two analyzed sounds.

Even though both the Cathedral's bells' sound and the witness sound have the same musical harmony, their 2D and the 3D various plots showed that rather significant differences exist between the two studied sounds, in terms of amplitude and intensity of the main upper partials. The presence of satellite partials in different number, frequency position and amplitude for the Cathedral's bells' sound as compared to the witness sound contribute in minor degree to the difference in sound perception.

Still, the complex analysis of sounds presented in this paper proves scientifically that even though bells seem to sound one like the other, in reality, each of them is unique. Even though the manufacturer tunes a ringing bell in the same musical harmony as other existing bells, small changes in shape, size, weight, wall thickness, composition of the material (the casting alloy), casting procedure all-together and even individual cooling method and duration needed to manufacture each bell will influence the resulting acoustical characteristics of that ringing bell, that can be identified only by scientific analysis [15].

References

[1] C. Oancea, C. Gheorghies and S. Condurache-Bota, Journal of Science and Arts, **1(12)** (2010) 199.
[2] W.A. Hibbert, *The Quantification of Strike Pitch and Pitch Shifts in Church Bells*, Ph. D. Thesis, Faculty of Mathematics, Computing and Technology, The Open University, Milton Keynes, 2008.
[3] J.H.E. Cartwright, D.L. Gonzalez and O. Piro, *A New Nonlinear Model for Pitch Perception* in *Statistical Mechanics of Biocomplexity* in *Lecture Notes in Physics,* D. Reguera, M. Rubi, & J. Vilar (eds.), Springer, New York, **527**, 1999, 205.
[4] N. Melniciuc Puica, Eur. J. Sci. Theol., **1(1)** (2005) 77.
[5] B.K. Nigjeh, P. Trivailo and N. McLachlan, *Application of modal analysis to musical bell design*, Acoustics 2002 – Innovation in Acoustics and Vibration. Australian Acoustical Society, Adelaide, 2002, 127-136.
[6] M. Ursescu, T. Maluțan and S. Ciovica, Eur. J. Sci. Theol., **5(3)** (2009) 71.
[7] ***, www.clopote.ro.
[8] ***, http://www.hibberts.co.uk/wavanal.htm#wavanal.
[9] ***, http://www.sigview.com.
[10] T.D. Rossing, D.S. Hampton, B.E. Richardson and H.J. Sathoff, Journal of Acoustical Society of America, **83 (**1988**)** 369.
[11] N.M. McLachlan and D. Cabrera, *Calculated Pitch Sensations For New Musical Bell Designs*, Proceed. of ICMPC7, Causal Productions, Adelaide, 2002, 600-603.
[12] R. Perrin and T. Charnley, J. Sound Vib., **90** (1983) 20.
[13] A. Lehr, Journal of Acoustical Society of America, **79** (2000) 1986.
[14] T.D. Rossing and R. Perrin, Appl. Acoust., **20** (1987) 41.
[15] A. Rupp, *Ringing Bells - State of the Art in the Durability Evaluation of Church Bells, Development and Evaluation*, LAVEK, Ljubljana, 2006, 1-14, available at http://www.probell.org/files/Ringing%20Bells-LAVEK%20Colloquium030306.pdf