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Design of a measurement methodology to characterize acoustic parameters and sound directivity of string instruments in a real acoustic environment

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Abstract

The directivity specifications and sound characteristics of an acoustic instrument are essential for a general use into the musical field. With this information, the musicians can select the adequate instrument for a specific purpose and the manufacturers can improve and advance in their designs. The study in this area also provides knowledge for virtual simulations and recording techniques. This research aims to disseminate a measuring methodology to characterize the acoustic parameters and sound directivity of a string instruments in a real acoustic environment. The design and development of a software capable to process data considering the ICE 61260 standard is promoted. It is exposed a method developed for an Amati model violin, using a continuous musical program touched with two different intensities by an experienced musician. The polar pattern results in both intensities are exposed with the sound characterization of the instrument through a spectral analysis.

Keywords: Directivity, polar pattern, violin

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1 Introduction

When the human begins to use the sound like an art of expression, a development era of devices capable of producing different type of sounds appears. Over the time, these devices denominated *instruments* start to be categorized [1]. At present, these instruments have both technical and acoustical specifications that represent their sound. One of these specifications is the directivity of the instrument, which indicates how the instrument distribute the sound pressure in the environment [2][3][4]. This specification is essential for the general use of the musical field, because it allows acoustic behaviour studies of the instrument in more detail to generate improvements in their designs [5][6].

Previous researches have exposed different methods to measure the directivity of a sound source. J. Baird and P. Meyer [7] measured a polar pattern of a loudspeaker in an anechoic chamber. In their method, the microphone was set in one position and the speaker was rotated. In L. Parati and F. Otondo research [8], is investigated which source is closer to the directional characteristics of a soprano's singer voice. To obtain the data, an array of fixed microphones in an anechoic chamber was used. The singer was rotated and was asked to sing isolated tones in two octaves. On the other hand, F. Otondo [9] [10] measured and compared the directivities of three musical instruments in a performance situation. The measurements were carried out using simultaneous recordings of 13 microphones in an anechoic chamber. Three different classical instrument were used and short isolated tones with a similar intensity was played. It concludes that the directivity has a direct influence on the sound field created in the room according to acoustical parameters. A. Canclini [11] investigated if there are any differences in the directivity measure of a violin leaving the musician located in predefined positions and leaving the musician free to move, assuming the positions needed for covering the positions of interest, holding the instrument in a standard and fixed location. Both measurements were made using tones and a plenacoustic camera for data collection. For the second method, a depth map camera was used to detect the movements of the musician. Unlike the other researches mentioned above and others [12] [13] [14] [15], this study was not conducted in an anechoic chamber because the authors believe that this type of room presents some issues for the musician. The violinist will be exposed only to the direct sound of the violin which typically provokes an annoying sensation that may impact on the naturalness of the performance. It concludes in their investigation that there are no significant differences between the two measurements. The proposed method presents the advantage of allowing the musician to play in a more natural fashion.

This investigation proposes a methodology to measure the polar pattern of a violin. Unlike the studies discussed above, this methodology uses a continuous musical program played by an experienced musician in order to do a musical analysis according to what the ear perceives [16].

The study was performed on the stage of a theatre to have more natural conditions for the musician's performance. The continuous musical program was played in two intensities in order to see possible differences in the directivity according to this phenomenon. Finally, the sound characterization of the instrument through a spectral analysis is exposed.

2 Procedure

2.1 Location

The measurement was conducted in the stage of a traditional theatre of Palomar, Tres de Febrero, Buenos Aires, Argentina. In that way, the musician could play in more natural conditions. The reverberation time of the stage was measured using the standard ISO 3382 [17] and with the main curtains closed. The impulse response method proposed by A. Farina [18] was used. The results were obtained in octave band and the average of the T_{60} was 0.2 seconds.

2.2 Instrument

The bowed string instrument selected was an Amati violin manufactured in Argentina. This type of violin follows the characteristics of the luthier and musician Nicola Amati (1596-1684). Its dimensions are: 58.5 cm long (35 cm box and mast 23.5), 21 cm wide, 3.5 cm thick and 74 cm of the bow. It is made of spruce wood (soundboard, bass bar and soul), European maple wood (back plate, ribs, neck and bridge) and ebony wood (fingerboard). The bow is made of carbon fibber.

Figure 1: Amati violin

2.3 Test Signal

The musician performed a musical program using the four strings of the violin in order to use all the frequency spectrum of the instrument. The duration of the complete musical program was 2 seconds. The music sheet is shown in Figure 2.

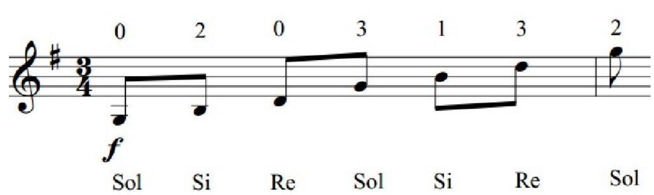

Figure 2: Musical program

2.4 Measurement equipment

The equipment used in this research was a measurement condenser microphone ECM8000 Behringer, a reference condenser microphone Shure PGA81, an audio interface Focusrite Scarlet 2i2 and a MacBook Pro computer.

2.5 Polar pattern measurement

The musician was placed on the stage with the instrument centred on the measurement axis. Absorbent material was placed on the floor in order to avoid the reflection of this area. A measurement microphone was located in the direct field of the instrument to 1.3 meters away from the bridge of the violin. The microphone was rotated every 5º grades in order to obtain the sound pressure levels on the horizontal and vertical planes (XY, XZ and YZ). The coordinates of each plane is shown in Figure 3.

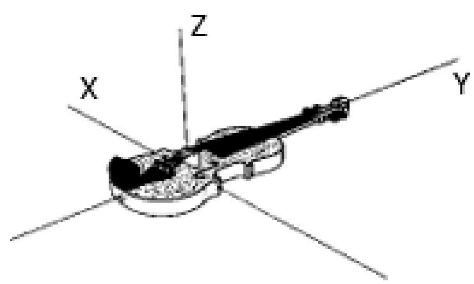

Figure 3: Coordinates of each plane

Before starting with the measuring, the musician tuned the instrument and performed some exercises to test the different intensities of playing. These were spaced approximately 20 dB. A second microphone (reference microphone) was located in 0º position in order to made a normalization of the sound pressure levels. In Figure 4 the musician location in the XZ plane is shown.

Figure 4: Musician location in the XZ plane

A software capable of recording and processing the audio signals was developed. Each audio signal was recorded in WAV format with a sampling frequency of 48 kHz and a resolution of 24 bits. In addition, and before each measurement, it was verified that the background noise level was 15 dB below the signal level.

After the recording session, all the audio signals were processed using a code that loads the measurement audio signal with the corresponding reference audio signal. The software uses octave band filters that are normalized under the standard ICE 61260 [19]. The time domain is transformed into the frequency domain by a Fourier Transform (FFT). The software gives the possibility to select the audio signal recorded in each particular grade and do the spectral analysis. The polar pattern of each plane is processed and the results are exported into a default template. In Figure 5 an example of the software is observed.

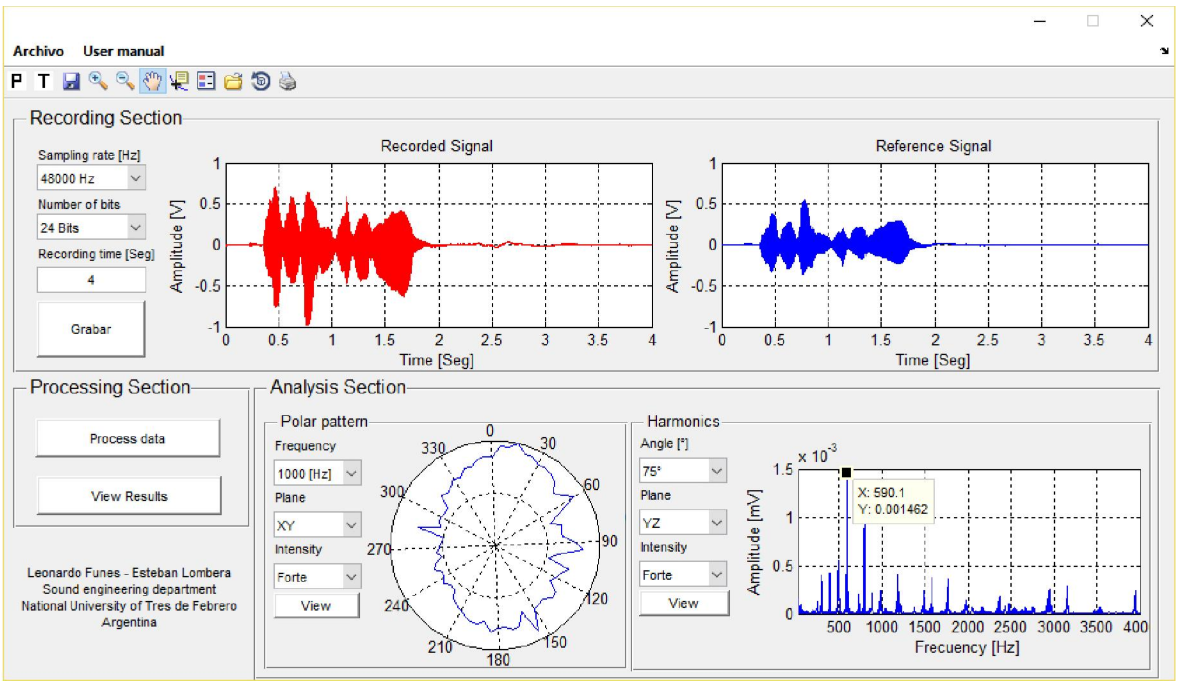

Figure 5: Developed Software

3 Results

The polar patterns in the XY, XZ and YZ plane are presented. In Figure 5 the directivity corresponding to the frequencies between 250 Hz and 8000 Hz in the horizontal plane XY are shown. In Figures 6 and 7 the directivity corresponding to the frequencies 250 Hz, 1000 Hz and 4000 Hz in the vertical planes are shown. The continuous curves represent the directivity of the violin in both intensities. The graphical scale goes from 0 to -45 dB in steps of 5 dB.

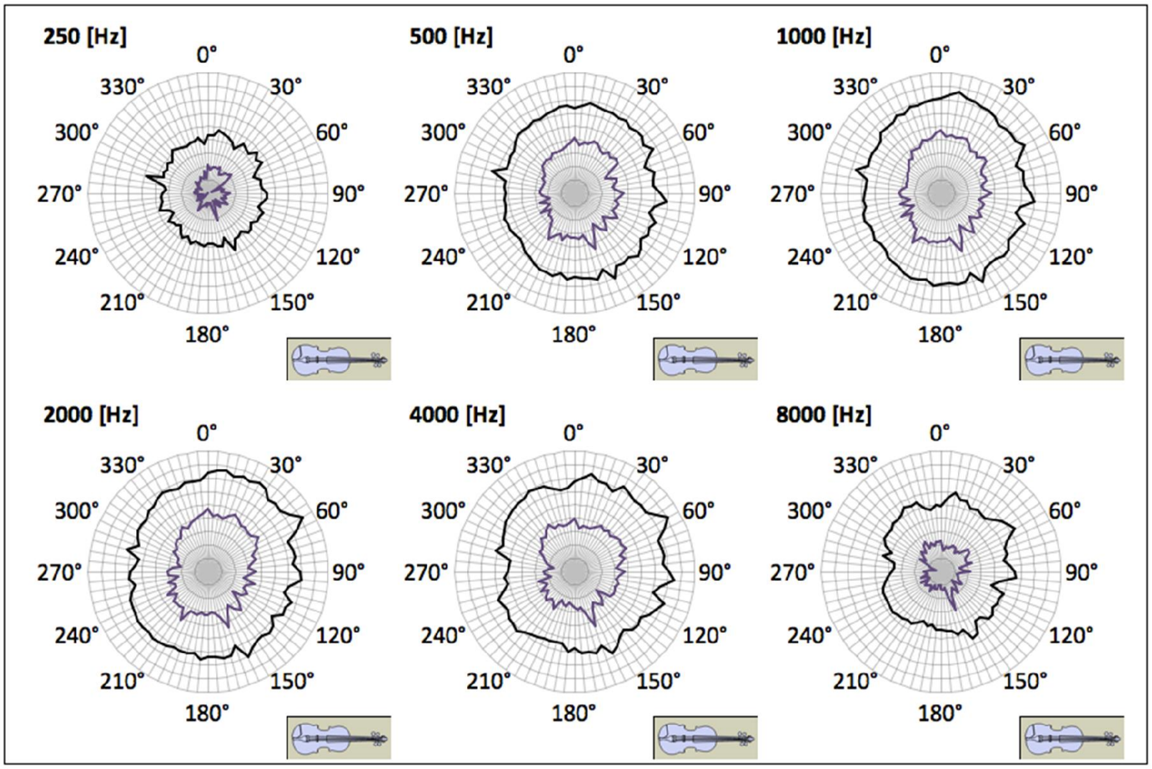

Figure 5: Polar pattern in XY plane

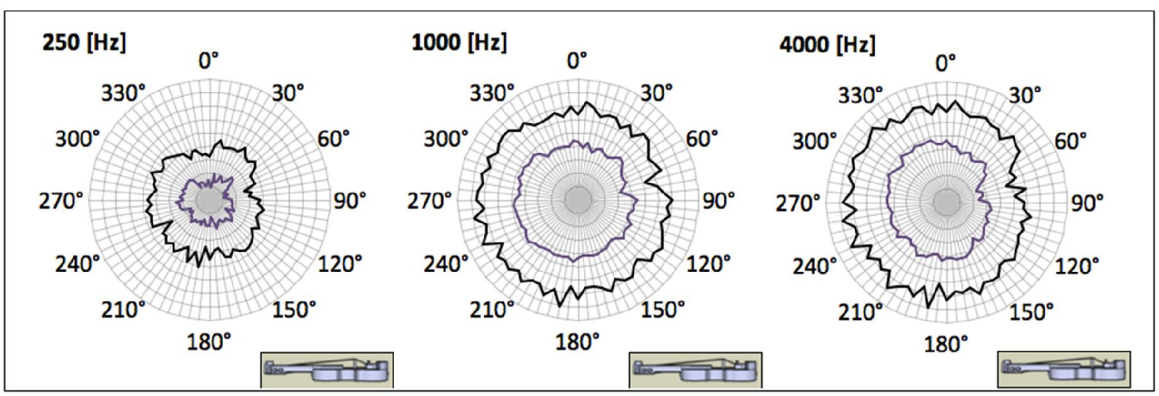

Figure 6: Polar pattern in YZ

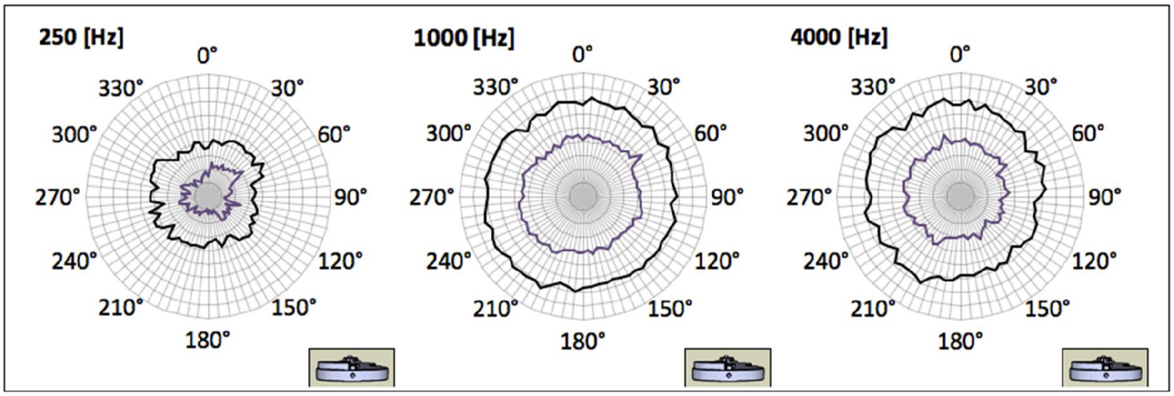

Figure 7: Polar pattern in XZ

In Table 1 the spectral analysis results of the musical program are shown. The positions evaluated correspond to 75°, 150° and 300° in all planes and for different intensities of execution. In the study of the frequency response various fundamental frequencies with their corresponding harmonics were observed. For this research, the fundamental frequency of greater predominance is analysed.

Table 1: Spectral analysis

Magnitudes [mV]						
Nota	**Plano**	**Intensidad**	**1° - 589 [Hz]**	**2° - 1183 [Hz]**	**3° - 1770 [Hz]**	**4° - 2375 [Hz]**
75°	XY	Fuerte	3,69	1,06	0,64	1,06
		Suave	0,69	0,29	0,17	0,2
	XZ	Fuerte	2,7	0,36	0,14	0,71
		Suave	0,32	0,08	0,07	0,09
	YZ	Fuerte	2,65	0,38	0,13	1,9
		Suave	0,48	0,08	0,02	0,19
150°	XY	Fuerte	2,76	0,61	0,39	0,22
		Suave	0,31	0,1	0,03	0,07
	XZ	Fuerte	1,59	0,24	0,13	0,48
		Suave	0,44	0,07	0,01	0,02
	YZ	Fuerte	1,1	0,43	0,03	0,1
		Suave	0,34	0,12	0,01	0,02
300°	XY	Fuerte	0,62	0,15	0,05	0,1
		Suave	0,21	0,02	0,01	0,01
	XZ	Fuerte	1,2	0,56	0,2	0,4
		Suave	0,26	0,11	0,02	0,04
	YZ	Fuerte	1,09	1,1	0,22	0,49
		Suave	0,37	0,23	0,05	0,12

4 Discussion

The directivity graphics of the XY, XZ and YZ planes are analysed. It is observed a change in the polar pattern for different frequencies in both intensities. For frequencies of 63 Hz to 125 Hz and 16 kHz, the sound pressure level for all the positions evaluated were too low to be appreciated. This may be due to the physical limitations of the instrument. According to the investigations [6], [11], [12] and [15] it can be observed that in all the planes, for 250 Hz to 500 Hz, the polar pattern of the violin tends to be omnidirectional. In the XY plane, for 1 kHz to 2 kHz the polar pattern presents more energy concentration in the front and the back side instead of the lateral sides. For the vertical planes, in 1 kHz, the directivity tends to continue omnidirectional. Then from 4 kHz to 8 kHz the polar pattern tends to be cardioid and a decrease of the sound pressure level at 270° in the XY plane and 90° in XZ - YZ planes appears. It is emphasized that this type of pattern is more visible in the XY plane and could be attributed to the acoustic shadow phenomenon produced for the musician.

It can be seen that the polar pattern corresponding to each frequency analysed (for all planes) tends to be constant (with some little variation) despite the intensity of execution.

The results of the difference in the harmonics amplitudes were analysed. In all planes, a low level of the third harmonic (odd harmonic) regarding to the second and fourth harmonics (even harmonics) is observed. The relationship between the level of the even harmonics and the level of the odd harmonic varies depending of the intensity of playing and the plane.

According to the paper presented by E. Arnold and G. Weinreich [20] the limitations of this research corresponds to human errors in the positioning of the microphone and errors in the instrumental used.

5 Conclusions

At first, it is concluded that the results obtained from measurements in anechoic chambers and the measurements presented in this research are similar.

With this investigation, it was observed that the polar pattern of a violin varies depending on the frequency and tends to be constant with different intensities of execution. Although, the directivity from each intensity of execution are not exactly the same. These little variations in the directivity could generate discrepancies in the sound perception of the instrument. These characteristics provide important information to the design of this instrument. Besides, the polar pattern provides information to improve the position of the violinist in a musical group (like an orchestra) and to developing microphones techniques.

Regarding the study of harmonics in the musical program and considering the studies by Schiffman [21], it is exposed that the instrument generally has a shiny timbre because the levels of the even harmonics prevail against to the level of the odd harmonics. However, this feature of the timbre will not remain constant because it depends on the different level of intensities and the different planes of radiation.

For future works, it is proposed to carry out the same study in other violins of the same model to generate repetitiveness and a standard feature of this instrument. It would be interesting to incorporate the directivity of this instrument in computer room simulations for future predictions. Also, the existence of directivities variations regarding to the velocity of a musical program execution should be analysed.

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