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Spherical mapping of violins

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Abstract
An original experimental approach oriented to the evaluation of the acoustic performances of violins is described. Starting from 14th Century the violins family have passed through significant changing, strongly influencing their sound. The "instrumental music" requires different parts for different voices: the violin family changes its mechanical structure following this requirement. The structural elements are modified in order to adequate the sound to the aesthetic taste of the historical period. Mechanical modifications involve geometry, relative positions and structural characteristics of fixed and mobile parts. The consequence is a significant alteration of vibration and acoustic responses.
The paper describes a systematic approach oriented to evaluate the acoustic performances of differently mounted violins (baroque, classical, modern) by means a spherical mapping of the generated sound. A workbench based on a semicircular structure carrying an array of 10 microphones interfaced to a portable acquisition unit, has been designed and realized. The violin, played by the musician in anechoic chamber or in representation room, is located at the centre of this semicircle: changing the relative angular position between the violin and the array acoustic spherical maps describing the actual sound emission are generated. A systematic comparison among differently mounted violins is shown and discussed.

1 Introduction

The mechanical modification undergone from the violin family in three centuries (from baroque to modern period) has involved all the fundamental components of these instruments: neck, fingerboard, bass bar, strings, bridge tailpiece, and sound post. This evolution has been conditioned by the necessity to adequate the sound performances of stringed instruments to the aesthetic taste of different historical periods. During the baroque period the violin family was conceived in such a way to emulate the different choral "voices" (bass, bassetto, tenor, contralto, soprano, falsetto), satisfying the difficulty to make single stringed instruments with large amplitude of registers.

During the 15th century strings was made using sheep bowels, light material particularly appreciated: but, as well known, the fundamental frequency generated by a vibrating string is inversely proportional to the square of its length and to its density. Consequently, to generate low notes is necessary to use or long or thick strings: in any case an unfavorable ratio between length and string diameter is produced. The result is high string inertias, generating rapidly dumped vibration and sound.

Baroque neck was flat, not backwards sloped and usually mounted using one or more nails: its geometrical shape doesn't allow to reach high notes and its simple but rough mounting influences the vibration modes at different frequencies, with significant fallout on the acoustic performances.

The bridge is a very significant component in a violin, realizing the mechanical connection between strings and harmonic plate. In a baroque violin it is rather rigid because the strings are thicker: the vibration transmission is increased, but the acoustic quickness is reduced. More detailed problems concern its aesthetic geometry and the correlation between this geometry and the vibration performance: but these aspects will be discussed in other specific papers. Anyway the dynamic force exchanged at the base of the bridge is a fundamental parameter to evaluate the mechanical excitation on the vibrating plate.

Baroque fingerboards were thick, flat and wedge-made: the tilt angle between bridge and strings is consequently reduced, allowing lower bridges but decreasing the duration of the generated sound.

Finally, baroque bass bar is shorter and slimmer, producing a lower damping effect but contributing to generate a silvery sound.

At the end of 17th century bowels strings are reinforced with metallic ropes: this choice allows the design of smaller instruments and within the classical series of violins some intermediate size of instruments disappears. In order to satisfy requirements of more virtuosity and more sound power new technical solutions oriented to easily reach high registers have been implemented. First of all a backwards-sloping neck: as consequence the bridge is taller, string angle increases and also the actual pressure on the soundboard increases. But from the acoustic point of view, increasing the string angle the bow attack position is modified and the violin becomes noisy. Attempting to solve these problems many lute makers propose new bridge geometries.

The evolution of the violins shows geometrical and mechanical modification until the 19th century: the neck is lengthened and embedded on the violin body and, consequently, the relative position between neck and soundboard is modified. The coming of steel strings allows the reduction of the string diameter, taking advantages on costs, tonality safety and mechanical stability.

Today philological musicians wish to play music as similar as possible to the origins and require to lute makers instruments correctly designed and assembled. Modern techniques of scientific analysis may strongly support the manufacturers, contributing to improve and preserve the Italian cultural heritage in the art of making stringed instruments.

At the University of Genoa (Italy) the multidisciplinary Centre of Research on Choral and Instrumental Music (MUSICOS) is strongly engaged to develop interdisciplinary theoretical and experimental researches on the mechanical and acoustic performances of different mounted violins. Hereafter the main results of compared acoustic experiments between baroque and modern instruments have been focused and discussed.

The approach is oriented to propose low cost methods easily reproducible not only in research laboratories or in anechoic chambers, but also in lute maker's workshops, in order to concretely support craftsmen in their activity of high level handicraft with modern diagnostic techniques usually unknown or not available in their studios.

2 The experimental approach

In order to compare the acoustic performances of different kind of violins and, more in general, of other acoustic instruments an original low-cost unit has been designed and realized.

The basic idea is to acquire acoustic information about the sound generated by different instruments, played both in anechoic chamber and in representation rooms. In order to reach this goal a rigid semicircular structure able to carry on an array of microphones has been designed and assembled.

Fig. 1. Overall view of the acoustic structure.

Figure 1 shows an overall view of the unit: it is conceived to carry 11 microphones: ten equally spaced on a semicircular array (1.5 m of radius) and one independent, as reference acquiring the background noise.

The musician sits on a rotating stool, equipped with an optical sensor: at the base of the stool twelve reflectors are located on an outer circle. The optical sensor emits a beam of infrared light and by its reflection detects the angular position of the stool. The relative position between musician and microphones allows locating the instrument (violin, viola...) at the centre of the arc. Starting from an initial angular position the musician plays the instrument (e.g. one single note can be played): the array of microphones simultaneously detects the sound and the corresponding signals are acquired by a multi channel acquisition system (Fig 2). Then the musician rotates on the stool and plays again: at the end of this sequence 120 signals are acquired (10 simultaneous signal for 12 angular positions). All the differences produced by the musician have compensated by the reference microphone signal, as discussed later on.

The described sequence can be repeated playing different instruments, in anechoic chambers, in representation rooms or in any other room. The acquired signal are analyzed and compared by means signal processing software (Test Lab, by LMS International). Spherical mapping are consequently generated: the comparison of emission responses in different regions of the virtual spherical surface enveloping the instruments makes available interesting information on their acoustic performances.

Fig. 2: Multi-channel acquisition and elaboration system.

3 Some experimental results

With specific reference to the comparison analysis of different mounted violins, experimental tests on baroque and modern violins have been developed. The best way to compare baroque and modern mounting is, of course, refers the study to the same instrument. Nevertheless this approach is difficult to be performed, because it requires making initially available, for instance, a modern violin and the possibility to disassembly the instrument after the first phase of experimental tests, transforming the mounting in a baroque geometry. This approach is, at the present time, under development: but acceptable results can be performed comparing two violins, modern and baroque, made by the same lute maker, having very similar overall sound powers.

Following the before described procedure, the initial significant comparison concerns the frequency response function (FRF): Fig. 3 shows the acoustic auto-power spectrum of two violins different mounted. The corresponding peaks are detected at lower frequencies for baroque mounting, due to typical differences of tuning. This result is representative of the overall contribution of the array of microphones: more detailed analyses can be performed playing a single note. Fig 4 (a, b, c and d) describes the frequency response on 1/24 of octave playing respectively single notes (E4, A4, D4, B5, G4).

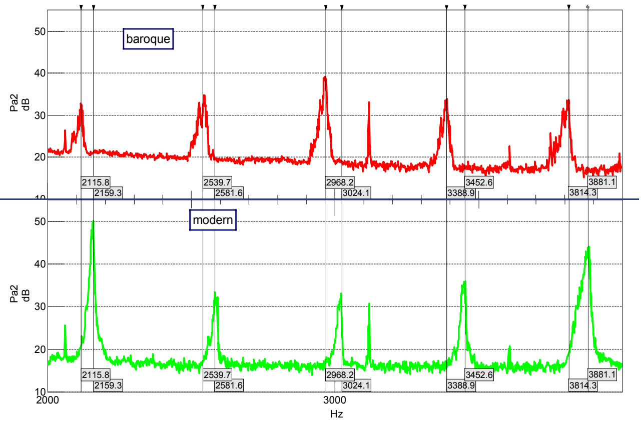
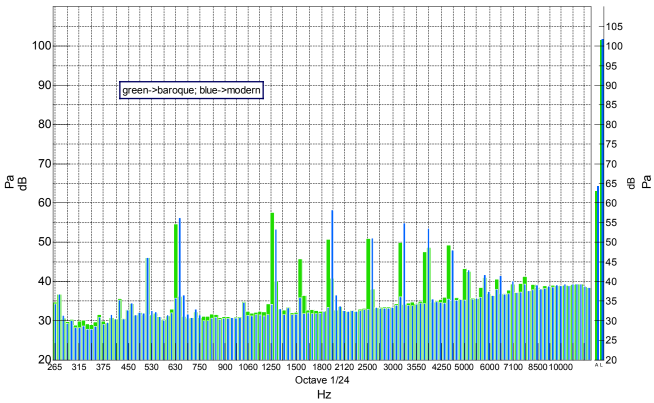
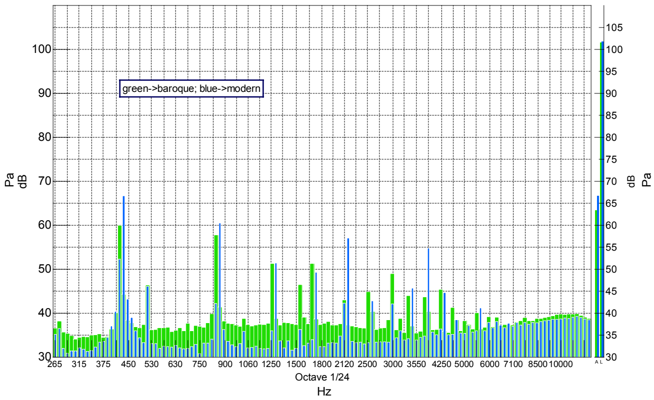


Fig 3: Sound pressure vs. frequency for baroque and modern violins.

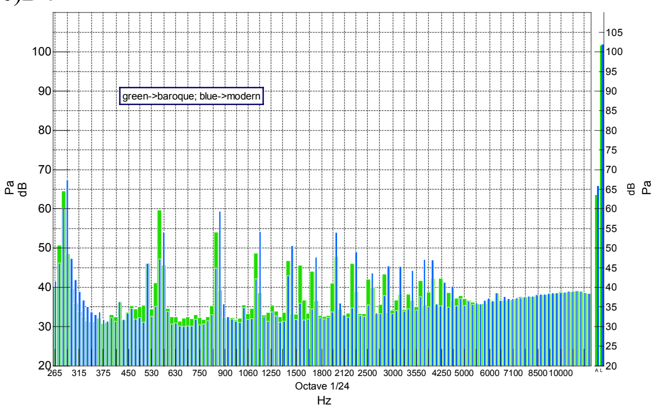
a) E4



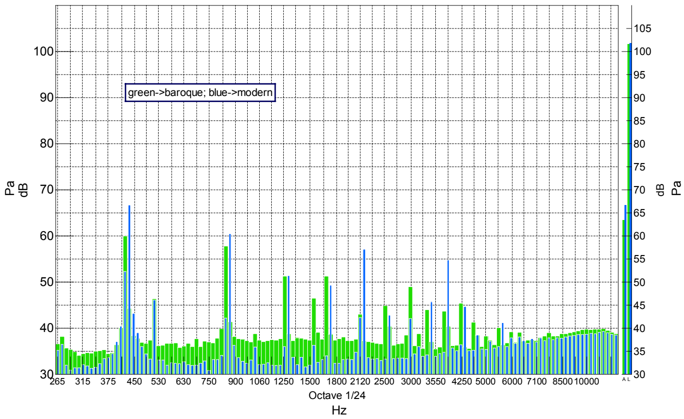
b)B4



c)D4



d) B5



e) G4

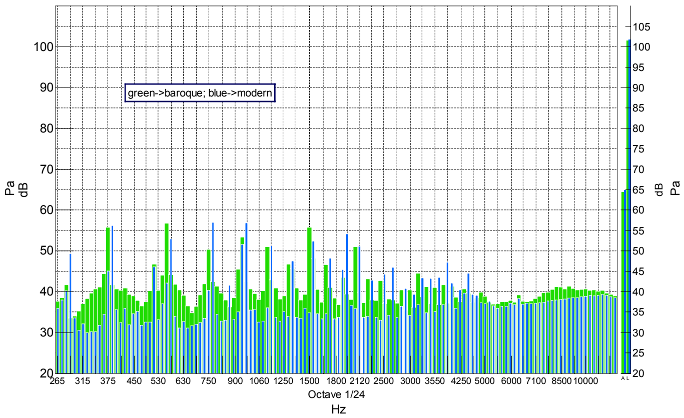


Fig. 4: Sound pressure vs. frequency (1/24 of octave).

The overall acoustic power spectrum of the violins under test is practically coincident, as shown in the column on the right (blue and green markers): but the acoustic contents at the various frequencies for the baroque violin (green line) are very different to the contents of the modern violin (blue line). This result is representative of the timber of the instruments.

The proposed equipment allows the generation of a spherical mapping for each instrument: the results can be collected for single frequencies or for range of frequencies. In order to show the potentialities of the proposed approach examples of comparison are reported hereafter.

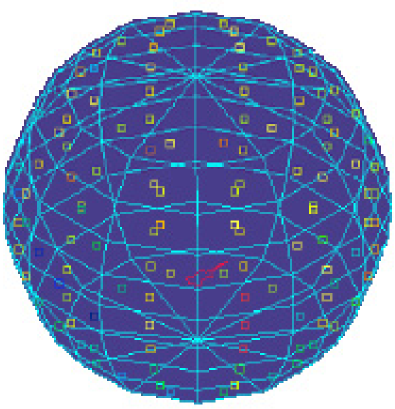


Fig. 5: Spherical mesh.

Fig 5 shows the spherical mesh defined by 120 points of measure around the instrument. The instrument is located in the geometrical centre of the experimental spherical mesh. The color palette is proportional to the acoustic pressure around the instrument: playing single notes the sound emission is presented as coloured maps. Tonalities change from blue (55 dB) to red (80 dB).

Figs. 6 and 7 collect the spherical mapping of a baroque and modern violins played on the note D4: the images correspond to very similar frequencies (846 Hz for baroque and 863 Hz for modern violin). Figs. 8 and 9 collect similar results in the same range of frequencies (250 – 2100 Hz).

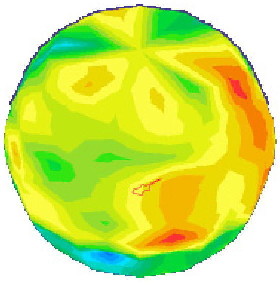


Fig. 6: Baroque violin at 846 Hz (note played: D4)

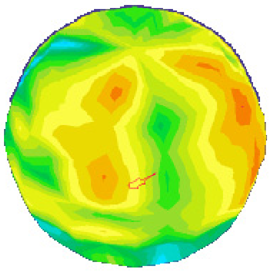


Fig. 7: Modern violin at 863 Hz (note played: D4).

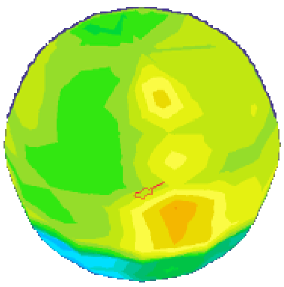


Fig. 8: Baroque violin in the frequency range 250-2100 Hz (played note: D4).

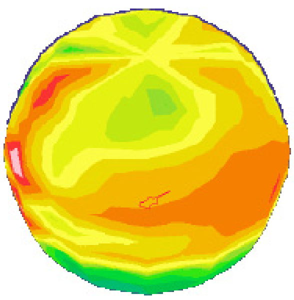


Fig. 8: Modern violin in frequency range 250-2100 Hz (played note: D4).

The acoustic performances are significantly different: in particular aspects of different directionality of the produced sound can be easily detected.

A systematic plan of experimental analyses has been organized, allowing a wide comparison among violins having different mounting or instruments having the same mounting but manufactured by different lute makers or made following different techniques of construction. Overall spectra in the frequency range 0 - 12500 Hz are evaluated: frequency upper limits are related to the acquisition unit, managing 11 independent channels. Figs. 9 and 10 show responses in this case: this kind of result is particularly interesting and useful because an immediate comparison on the explored range of frequencies is monitored.

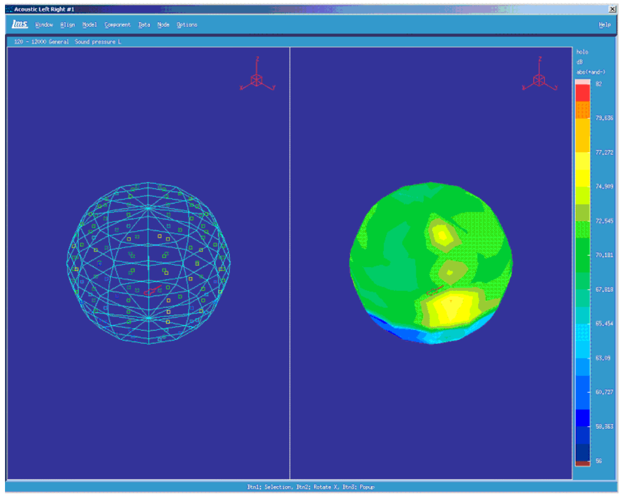


Fig. 9: Baroque violin: overall response (0 - 12500 Hz).

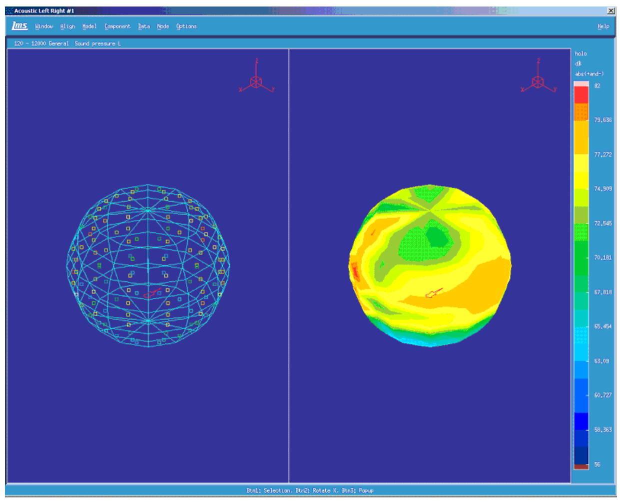


Fig. 10: Modern violin: overall response (0 -12500 Hz).

Limits of space don't allow in this paper to further detail this analysis: Figs. 11 and 12 report respectively the bottom-up and the top-down views for a baroque violin (B) and for a modern violin (M), played on notes G3, D4, A4, E4, B5.

Differences of acoustic directionality are evident and can contribute, for instance, to explain the different role played by violins within musical ensembles and orchestras in the evolution from chamber music to theatre music.

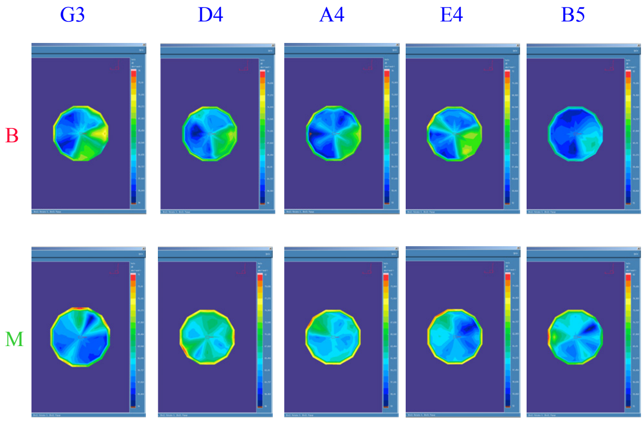


Fig. 11: Bottom-up view of spherical maps
(B: baroque; M: modern).

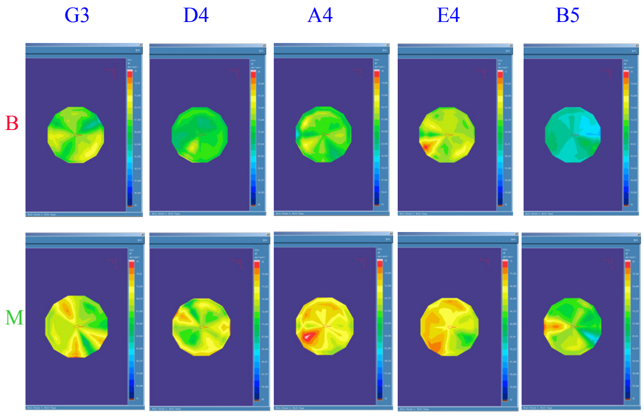


Fig. 12: Top-down view of spherical maps
(B: baroque; M: modern).

In addition, the spherical maps can be animated (Fig. 13), showing the effect of the sound pressure around the instrument. Finally, the corresponding pressure signals can be transformed in acoustic signals, generating a sound map of the acoustic pressure.

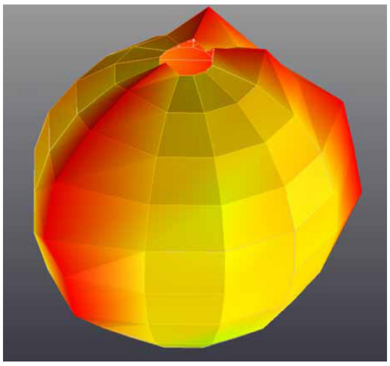


Fig. 13: Example of animated map.

4 Background noise

An independent microphone, located on the experimental unit, acquires the background noise. It allows two different analyses:

- the background noise before playing the instrument;
- the compensation of signals corresponding to different positions of the musician, taking into account that the player is not able to exactly generate the sound repeating the same musical excerpt.

Fig. 14 reports an example of background noise acquisition.

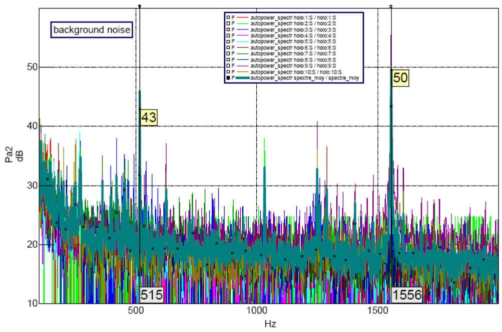


Fig. 14: Background noise acquisition.

The RMS average power spectrum (in dB) of 10 microphones is analysed in the frequency range 0 - 2000 Hz and compared to RMS reference for each microphone. The ratio defines a factor used to scale each acquisition before the mapping generation.

5 Conclusion

An original approach of experimental mapping of sound generated by violins is proposed. A low-cost unit has been designed and realized and comparisons between violins having different mounting (baroque and modern) are developed. The proposed approach can be applied for the evaluation of the acoustic performances of a wide spectrum of instruments, played both in anechoic chamber and in representation rooms. Further developments are oriented to optimize the detection unit, increasing its flexibility and dexterity and allowing the acoustic acquisition on circular arrays with variable diameters.

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