Spectral Properties of Orchestral Instruments Measured in the Concert Hall of a Public School

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Abstract: This paper presents the spectra of several orchestral instruments measured in the concert hall of the Liceo Statale “Alfano I” in Salerno, Italy. For each musical instrument used the variations of frequency of average signal unweighted (LZeq average) relative to the C diatonic major scale are shown in ascending and descending order. In this study the notes played by eight instruments (flute, trumpet, bass tuba, drums, violin, horn, piano and tenor sax) in an acoustically correct room are measured using a class A phonometer from which frequencies are derived. The most important data relating to performances of each instrument were processed in order to provide a useful database both for designers who deal with predictive analysis for the acoustic design of concert halls and those who digitally simulate sounds produced by orchestral instruments.

Key-Words: Acoustical Measurements, Musical Instruments, Spectra Analysis, Diatonic Major Scale

1 Introduction
Music signals, like many other non-stationary signals we encounter in practice, such as speech, seismic activity, machine vibrations, and biological signals exhibit time variable or non stationary characteristics [1] Therefore it is useful to apply to such signals frequency analysis, providing a characterization of signals in terms of frequency content to study their changing spectral properties. Music content analysis in general has many practical applications, including structured coding, database retrieval systems, automatic musical signal annotation [2]. The analysis of orchestral instruments is a very important problem of old standing. It has been addressed on various occasions both by physicists and psychologists, dating back to the days of Helmholtz’s work with his resonators [3]. This paper presents the spectra of several orchestral instruments obtained by a measurement session in the concert hall of the Liceo Statale “Alfano I” in Salerno, Italy. In carrying this out, it has been thought useful to measure individual instruments playing short pieces of music together as an orchestra, rather than single notes to measure them in such a way as to obtain an average of distribution of amplitudes in terms of frequency. A wide set of features covering spectral properties of sounds was presented and the most important data relating to performances of each instrument were processed in order to provide a useful database both for designers who deal with predictive analysis for the acoustic design of concert halls and those who digitally simulate sounds produced by orchestral instruments. In particular, in the software used by designers for acoustic predictive analysis it is very important, in order to achieve actual and not estimated results, making use real data from the sound sources in the room. In this case it was considered particularly useful to determine in an acoustically correct room the sound pressure levels of the named instruments. With regard to each instrument graphs are shown relating to the performance of the sound pressure levels in the frequency domain.

2 Measurement session
At first, in order to verify the correctness of the acoustics in the Concert Hall of the Public School “Liceo Statale Alfano I” in Salerno, where are conveniently located on the walls and ceiling some acoustic panels in low-density polyethylene foam with calibrated closed cell structure (Stratocell® Whisper® ), the average reverberation time was measured at various frequencies using Integrated Impulse Response, in accordance with the international standard ISO 3382- "Measurement of the reverberation time of rooms with reference to other acoustical parameters".
Only professional musicians were employed for the tests. In each case the musician was instructed to play (except for the drums) a C major diatonic scale - one octave ascending and one descending. Using a class A phonometer Larson Davis model 831, placing the microphone at 1 meter from the acoustical source and a height of 1.5 m, sound pressure levels were measured.

![Figure 1 - Picture of the concert hall](image)

Figure 2 shows that the reverberation time at the frequency of 500 Hz falls in the range indicated in the literature for a room of this volume and type and its variation in frequency in the range of 250-4000 Hz is also similar to that in the literature.

The orchestral instruments played in the concert hall were:

- Transverse Flute Yamaha 517: closed holes, offset G, E-mechanism, silver headjoint, headjoint type AM, with C-feet, silver plated.
- Bass Tuba Yamaha Established in 1887: 4-valve compensating system, Bore size: 0.689–0.728" (17.5–18.5mm), Bell diameter: 19" (480mm), Four sprung water keys, Wooden shell case with wheels.
- Drums Sonor Smart Force Series, Color: Brushed Copper (Chrome Shell Hardware), Set containing 22"x17.5" Bass Drum thomann, 12"x09" - 13"x10" Tom Toms, 16"x16" Floor Tom, 14"x5.5" Snare Drum, DTH Doubletomholder, 4-pcs doublebraced Hardwarepack containing Hi-Hat Stand, Snare Stand, straight Cymbalstand, Bass Drum Pedal, 9-layer 7.2mm thickness Poplar Wood Shells, Sonor Designs Tune Safe thomann Tuning Lugs, Ball Clamp Doubletomholder.
- Violin A. Pivetta pupil of S. Scarampella, Mantovana School, end of 800: length of back 358 mm.
- Horn Paxman 50 m: F / Bb, Yellow brass, Bell unscrewed, Mechanics fixed, Without lacquering.
- Piano Libermann GP 170: Extruded aluminum, Beams Walnut, Bridges Vertically laminated with maple cap, Fallboard Slow fall, Hammers T-stapled 22 lbs premium felt, Key bed material Butcher-Block-Spruce, Pinblock 19 cross ply maple, Tuning pins Nickel plated steel, cut-thread, Length 5’ 7”, Weight: 820 pounds.

### 3 Results

In this section frequency characteristics of all orchestral instrument used are reported. LZeq average is a measure of the average sound pressure level equivalent during a period of time T in dB without any correction (Z is for Zero frequency weighting, which implies no frequency weighting. In reality the range is 10 Hz to 20 KHz ±1.5 dB):

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L_{eq} = 10 \log \left( \frac{1}{T} \int_{-T/2}^{T/2} \left| \frac{p(t)}{P_{ref}} \right|^2 dt \right)
\]
4 Conclusion
This paper presents the spectra of several orchestral instruments (flute, trumpet, bass tuba, drums, violin, horn, piano and tenor sax) obtained by a measurement session in the acoustically correct room concert hall of the Liceo Statale “Alfano I” in Salerno, Italy. For each musical instrument used the variations in respect of the frequency of average signal unweighted (LZeq average) relative to the C major diatonic scale - one octave ascending and one descending- are illustrated. The results provide a useful database both for designers who deal with predictive analysis for acoustic design of concert halls and those who digitally simulate sounds produced by orchestral instruments.

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References: