SOME CONSIDERATIONS ON SOUND PROPAGATION IN A CYLINDRICAL WORSHIP SPACE

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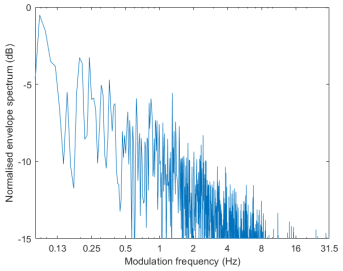
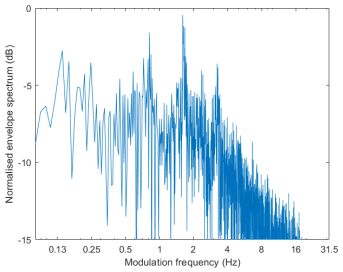
ABSTRACT

St John's Baptistery in Pisa is an outstanding large-scale medieval architecture with a particularly high reverberation time. In 1987 the building was awarded by UNESCO as World Heritage Site together with the surrounding square [1]. The architecture is a composite symmetrical central-plan space, hosting several coupled volumes such as the galleries - the so-called "matroneum" - and the conical dome. Previous works concerned the acoustic calibration of the numerical model of the space [2]. The geometrical features, the sound energy decays, the flutter echoes, and the whispering-gallery effect contribute to an extraordinary sound environment [3, 4]. The optimal range of reverberation time usually considered in worship spaces - intended both for music and speech - might reveal that the Baptistery is inadequate to liturgical use [5]. Nevertheless, the analysis of the evolution of choir music allows to understand the actual suitability of this particular worship space to its use over the centuries. The medieval liturgy was not focused on the speech intelligibility, but on the perception of listening envelopment. In Western Catholic churches the liturgy was celebrated in Latin until the mid 20th century (2nd Vatican Council, 1962-1965). Gregorian chant was performed only by clergy following macro-sequences of vocal emissions which corresponded to syllables of Psalm verses. No time indication was provided: the performance was not note-based until the 13th century. The reverberation of the Baptistery could prove to be an optimal support to the listening of Gregorian chants on this basis [7]. Two methods will be employed in the present study to demonstrate the latter assumption: the first one based on spectral amplitude of modulation and the second one based on effective duration of the autocorrelation function.

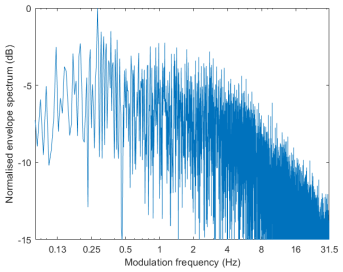
The first method considers the choir music as a combination of a modulated carrier - the sung note - and the modulation signal, that takes into account the temporal behaviour of the singing process. The reverberation deteriorates the information if its value is higher than a certain limit, but at the same time the reverberation enriches the voices and increases the chant loudness. The spectral amplitude of modulation shows how many information is carried by which modulation frequency [8, 9]. Three anechoic



(a) Kyrie (14th C.)



(b) Almighty (17th C.)



(c) Speech

Figure 1. Normalised envelope spectra as functions of modulation frequency [2].

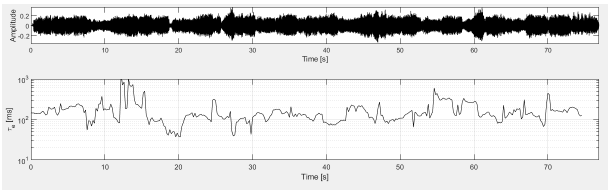
excerpts are analysed:

1. the cantus firmus excerpt "Kyrie" by Guillaume de Machaut (1300-1377), recorded *ad hoc* and freely available in a repository [10];

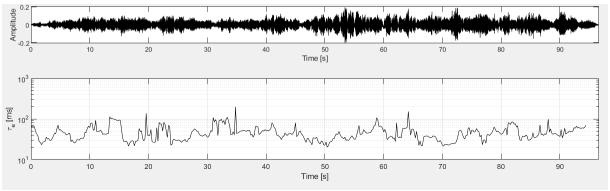
2. the baroque piece "Almighty and Everlasting God" by Orlando Gibbons (1532-1625) (Freheit, 2005);

3. a speech radio recording, which can be assumed as anechoic.

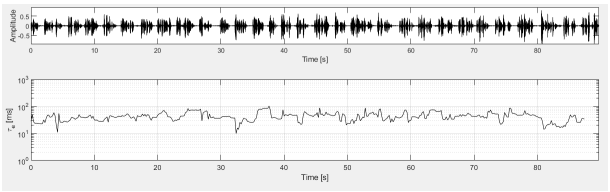
Spectral amplitude of modulation was extracted from each motif and then normalized in Matlab (see figure 1). The *Kyrie* shows the maximum at low modulation frequencies - around 0.2 Hz - while the baroque excerpt shows its maximum at higher modulation frequencies, around 2.0 Hz. The lower the modulation frequency, the higher the reverberation time necessary to improve the intelligibility of the excerpt. Moreover, in the *Kyrie* excerpt from a certain modulation frequency onwards ($f_m = 2$ Hz) the values are lower than 10 dB compared to the maximum, meaning that the corresponding information content is negligible. If the function in frequency has a slighter slope, as the case of *Speech* and *Almighty*, the two signals carry information at high modulation frequencies and thus, they need lower reverberation time to be properly 'demodulated'. That is the reason why Speech Transmission Index could result meaningless when used to analyse Gregorian chants.



(a) Kyrie (14$^{\text{th}}$ C.) $\tau_e \simeq$100-200 ms



(b) Almighty (17$^{\text{th}}$ C.) $\tau_e \simeq$40-80 ms



(c) Speech $\tau_e \simeq$20-40 ms

Figure 2. Temporal behavior of the effective duration of the autocorrelation function for each anechoic excerpt under study (integration time $T = 2$ s over rectangular time windowing, step$= 0.2$ s) [11].

The second analysis is based on the temporal similarities. Using the same anechoic excerpts, the information carried is investigated through a short-time analysis, instead of the whole signal length. The metric used is the effective duration of the autocorrelation (τ_e) which can span from 10 ms (impulsive consonants) to more than 200 ms (organ music). In the present paper the reverberation time is considered at mid frequencies (500-1000 Hz) and τ_e value is averaged over time, returning a single value (see the approximated range in figure 2). In the case of *Kyrie*, values span from 100 to 200 ms, while for *Almighty* the averaged value is around 60 ms. *Speech* shows lower values, meaning that there are faster variations in each short-time window. According to previous literature, results show that the preferred reverberation time is around 5 s for Gregorian chant, 1.5 s for baroque chant, 700 ms for contemporary radio speech. These values may be read as an increasing influence of the text in the choir music. For all these reasons, St John's Baptistery could be considered an optimal room for Gregorian chant, even if it is an outlier from other worship places and its criteria exceed from the recommended ranges [2].

1. REFERENCES

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