High-resolution 3D directivity measurements of a trumpet

Andrea Corcuera Marruffo[1], Jithin Thilakan[2],
Alex Hofmann[1], Vasileios Chatziioannou[1] & Malte Kob[2]

[1] *University of Music and Performing Arts, Vienna Email: {corcuera-marruffo, hofmann-alex, chatziioannou}@mdw.ac.at*

[2] *Detmold University of Music, Germany Email: {jithin.thilakan, malte.kob}@hfm-detmold.de*

Introduction

Musical instruments have often been the focus of research on measurement and simulation of the radiation characteristics of sound sources. First investigations on directivity patterns of musical instruments were carried out by Jürgen Meyer in the 1970s [1]. Since then, numerous other researchers have conducted studies on sound source directivity, like M. Pollow et al. [2] and Pätynen et al. [3], who measured the directivity of a large collection of orchestral instruments using 22 and 32 microphones, respectively, placed around the musician. Due to the difficulties in providing a repeatable excitation, the directivity patterns of musical instruments are often obtained using spherical microphone arrays that measure simultaneously at several locations around the source. However, this results in patterns with low spatial resolutions. Repeated-capture measurement systems, on the other hand, don't have such a strict limitation on the spatial resolution, which has favoured their use for measuring high-resolution patterns of musical instruments using artificial excitation [4, 5] or musicians [6]. Although measuring directivity patterns with artificial excitation ensures repeatability of the results, measuring musical instruments with this method does not include the natural excitation of the source nor the acoustic influence of the musicians, who are intrinsic to the source. On the other hand, when using repeated-capture systems with musicians, repeatability of the excitation can't be guaranteed.

In this paper, we present an approach to take the acoustic shadowing of the musician into account, the measurement setup and the obstacles faced during the recordings of high-resolution directivity patterns of a trumpet. Measurements were done in 3D using artificial excitation, a turntable and a mannequin attached to the setup that allowed to obtain an approximation of the acoustic effect of a musician in a performance. The high-resolution directivity patterns are available for use in academic research[1].

Method

The measurements were done in the anechoic chamber at the University of Applied Sciences and Arts Ostwestfalen-Lippe (TH OWL, Lemgo, Germany). The measurement chamber has inner dimensions of 4.80 m x 5.80 m x 4.00 m and a grid floor to minimize reflections.

An automated turntable (Fouraudio ELF Turntable) with 3 degrees of freedom was used to obtain 3D directivity patterns of a standard B_b trumpet with no valves pressed. Two measurement microphones (NTI M2010) were placed at a distance of 1.5 and 2 meters from the centre of the setup.

Figure 1: Setup used for the measurement of a trumpet in 3D measurements with a mannequin and a turntable.

The measurements were performed with and without a standard mannequin. Only the head and torso of the mannequin were used (approximately 90 centimetres height, 50 centimetres width), which were covered with clothes to simulate realistic effects and avoid strong reflections. The spatial resolution was 5° in both cases, using an equal-angle sampling strategy along azimuth and elevation, resulting in 2522 unique measurement positions. Due to the characteristics of the measuring system, the poles of the measurement grid are located in front of and behind the instrument.

The instrument was excited artificially using a horn driver (3B 1000811) attached to the mouthpiece coupled with a rubber. A sine sweep of 1 second duration was used as the input signal and three measurements were performed and averaged for each measurement point. The turntable and the recordings were both controlled by WinMF, an acoustic measurement software typically used for loudspeaker measurements. The frequency responses were obtained via deconvolution and given in .spk format. Recordings were done with a sampling frequency of 48 kHz.

For the 3D measurements without a mannequin, the trumpet could be mounted with its bell at the centre of the turntable's axis of rotation. However, in or-

[1] `https://www.doi.org/10.5281/zenodo.6401417`

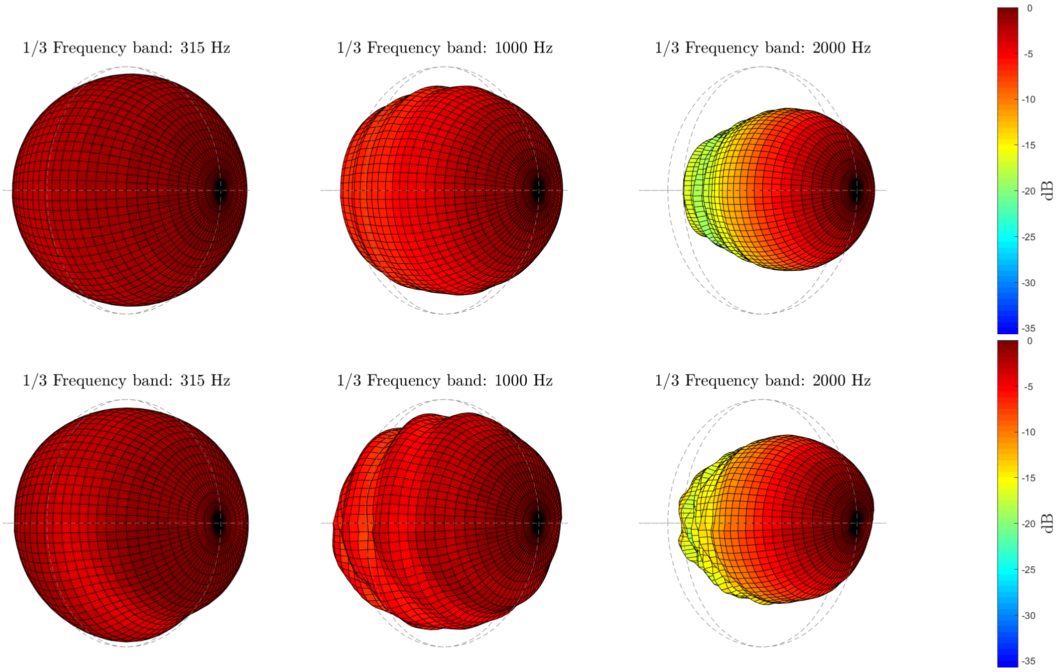

Figure 2: Normalised directivity balloon plots of a trumpet at 2 meters at 315 Hz, 1000 Hz and 2000 Hz third octave bands without (upper row) and with (lower row) mannequin. Trumpet's bell pointing to the right.

der to measure the trumpet with the mannequin, the setup had to be changed. The mannequin was attached to the turntable using a perforated plate, which also held the claws that gripped the instrument and loudspeaker. While this solution allowed us to approximate the player's influence on the directivity patterns, it constrained us in terms of where the instrument and loudspeaker could be placed. The first thought was to place the trumpet at the same level as the mannequin's mouth. This, however, would imply that the loudspeaker was mounted on the side of the head and that the instrument was not placed along the turntable x-axis or y-axis. Therefore, the instrument and loudspeaker were moved beneath the mannequin's chin, such that the bell of the trumpet was aligned with the y-axis. As a consequence, the instrument was shifted forward, since the turntable arms were too short for centring the setup at the trumpet's bell with the mannequin. The centre of rotation was, therefore, closer to the mouthpiece, that is, 40 centimetres behind the bell. A simplified approach based on the cosine's law and inverse distance law was used to determine the offset distance and level compensation, respectively. Acoustic centring methods can be used to compensate for this misalignment, however this is outside the scope of the article.

Results

Figure 2 shows the directivity of the instrument, normalised to the maximum radiation value, in the form of balloon plots at three different third octave frequency bands: 315 Hz, 1000 Hz and 2000 Hz. The colour and the radius of the balloon plots are both scaled according to the value indicated in the colour bar.

As seen in Figure 2, the directivity patterns are highly symmetrical with respect to the instrument axis, which is more evident when measuring the instrument alone. With its 90 centimetres size, the mannequin already constitutes an obstacle at low frequencies from around 350 Hz, and appears to affect the measurements at low frequency bands, as can be seen in Figure 2 (lower row, left). Both obtained patterns, with (lower row) and without (upper row) the mannequin, show an omnidirectional behaviour at low frequencies and a more directive pattern towards the bell as the frequency increases. Middle frequencies, from 1000 Hz, exhibit mild side lobes that become narrower and increase in number with frequency. With the used 5° resolution and averaging the patterns in frequency bands, however, very narrow lobes at higher frequencies can't be clearly observed.

The trumpet shows a pronounced directional effect towards the direction of the bell that is evident as frequency increases. This can be seen reflected in the large front-back-ratio (FBR) values at high frequencies (figure 3), defined as the ratio in dB between the power radiated to the front and the back. The FBR is, nevertheless, almost the same when the pattern is measured with a mannequin as with the instrument on its own. Therefore, for brass instruments with bells emitting the sound to the opposite side of the musician, this metric is not very informative. Thus, other metrics should be explored to get a more accurate picture of the effects induced by the performer. A large difference in the FBR for the two measurements is only observed in the 4000 Hz frequency band, but this could be due to some loudspeaker leakage, attenuated at the rear by the mannequin. However, the effect of the loudspeaker on the patterns remains to be studied.

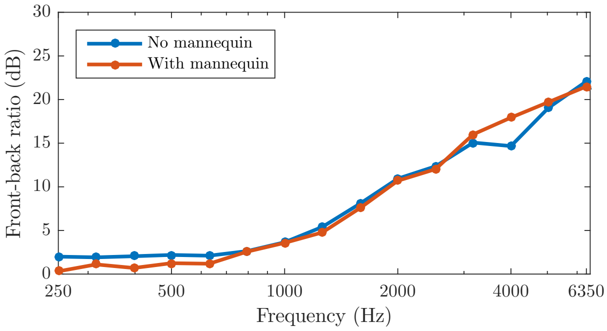

Figure 3: Front-back-ratio (FBR) values in dB for the trumpet with (red) and without (blue) a mannequin at 2 meters in third octave bands.

Nevertheless, it can be observed that the mannequin introduces some small effects that would be expected if a musician was present.

Conclusion

This paper outlines a method for obtaining the directional characteristics of a musical instrument in high resolution using a repeated-capture system while taking into account the acoustic shadowing of a player through the use of a mannequin. Although repeated capture systems allow very high-resolution patterns to be obtained, this method can lead to inaccurate results when used with real players, as they potentially introduce repeatability errors in the results. A solution would be to use a mannequin that simulates the acoustic effect that a musician would cause in the patterns.

Results of an experimental setup with a trumpet and a mannequin show the effects that a player has in the directivity patterns already at low frequencies. The instrument under study was a highly directional source with one main lobe pointing toward the opposite side of the player, so the mannequin has a relatively small effect on the obtained patterns. However, future work should investigate other instruments with more complex directivity characteristics, as they might show stronger effects of the player's acoustic shadowing and underscore the important role that the player has when studying directivity patterns. Moreover, a sophisticated mannequin with an integrated excitation system could be used in future measurements to obtain more accurate results.

Acknowledgements

Thanks to TH Ostwestfalen-Lippe for the possibility to use the anechoic chamber. This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie Grant Agreement No. 812719.

References

[1] Meyer, J. (2009). Acoustics and the performance of music: Manual for acousticians, audio engineers, musicians, architects and musical instrument makers. Springer Science & Business Media.

[2] Pollow, M., Behler, G., & Masiero, B. (2009). Measuring directivities of natural sound sources with a spherical microphone array. In Proc. of the Ambisonics Symposium (pp. 166-169).

[3] Pätynen, J., Lokki, T. (2010). Directivities of symphony orchestra instruments. Acta Acustica united with Acustica, 96(1), 138-167.

[4] Grothe, T., & Kob, M. (2019). High resolution 3D radiation measurements on the bassoon. In Proc. of ISMA.

[5] Corcuera Marruffo, A., Mayer, A., Hofmann, A., Chatziioannou, V., Kausel, W.: Experimental investigation of high-resolution measurements of directivity patterns. DAGA (2021)

[6] Bodon, K. J. (2016). Development, evaluation, and validation of a high-resolution directivity measurement system for played musical instruments. Brigham Young University.