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3D room acoustic measurements with low cost equipment

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ABSTRACT

Measuring 3D Room Impulse Responses (3DRIR) provides significantly more information about a room than can be captured with standard omni-directional measurement system. However generally the use of this technology has been limited to auditoria and other specialist spaces due to the cost of the specialist equipment and the time required for the measurements. This paper describes how battery powered consumer grade equipment can be utilised to create effective 3DRIRs faster and cheaper than existing industry standard systems. The advantages as well as limitations are discussed.

1 INTRODUCTION

The methods for the measurement of room acoustic parameters are outlined in ISO 3382-1:2009. Measurements conforming to this standard have traditionally been undertaken with an omnidirectional microphone and dodecahedron loudspeaker. An additional figure-of-8 microphone has been used when Lateral fraction (J_{LF}) or similar metrics are required. Modern measurement systems generally utilise a swept-sine or MLS measurement signal in accordance with ISO 18233:2006.

More recently, compact microphone arrays have been used to enable more detailed directional information to be captured. As well as enabling typical ISO 3382-1:2009 parameters to be measured, these compact arrays enable capture of full 3DIRs. The most common form of array consists of 4 cardioid microphones in a tetrahedral pattern. The signal captured by these microphones, as A-format, is converted into the more commonly used ambisonic B-format. The B-format 3D impulse responses can be processed to provide information on the direction of sound arrival (Protheroe, Guillemin, 2013) and can also be utilised to provide realistic 3D auralisations. The compact arrays can also generate figure-of-8 patterns that can be utilised to measure Lateral Fraction (J_{LF}). By using the same array for both the omni and figure-of-8 pattern, error introduced in the calibration of different microphones can be avoided (Protheroe, Day, 2015).

ISO 3382-1:2009 requires the use of an 'omnidirectional' speaker. Most measurement systems use a dodecahedron shaped loudspeaker with individual wide range drivers per facet. A typical measurement grade dodecahedron would have an overall diameter of 350 mm and drivers of diameter 130 mm. The power amplifier can be separate or located within the loudspeaker. The system is generally mains powered with a weight of approximately 10 kg.

1.1 Limitations of the current system for common use

For a compact microphone array to provide accurate directional information the signal from each direction must be very evenly matched. This requires accurate calibration of microphone capsules and also very precise gain matching of the microphone channels. In practice a preamplifier with digitally controlled gains is required to enable accurate matching. To avoid the need for 4 separate microphone cables, conversion boxes that send analog audio through ethernet cables can be used. Alternatively, an audio-over-IP system such as Dante can be used.

The dodecahedron speaker is moderately heavy and requires power and a signal input. Because the source speaker is generally moved less than the microphone and is more difficult to move, it is common for the controlling computer and interface to be closest to the source. In large spaces this arrangement effectively necessitates a 2-person measurement operation. One person controls the measurements and moves the source speaker. The other person moves the microphone between receiver positions.

The above set-up works well for large performing arts spaces where the accuracy of the measurements is of prime importance. However, because the cost of equipment and the significant time required to undertake measurements, it is often not used in smaller spaces such as classrooms, meeting rooms, lecture theatres and studios. It is the author's experience that using 3D measurements in these spaces can be very useful in diagnosing issues that would not be seen in a traditional omnidirectional reverberation time measurements. An example would be a classroom with lots of ceiling absorption but minimal wall treatment. With a 3D measurement of the space it would be possible to see how sound reflecting between walls was creating a '2D field' and resulting in a much longer RT than would be expected based on the overall absorption.

In 2020, Marshall day Acoustics were approached by the Ministry of Education to develop a system to measure the room acoustic performance of a large number of classrooms within New Zealand. The system needed to be cost effective, portable and easy to use. The results of the measurements were to be used to identify need for remedial treatment. From our experience, using a 3D measurement rather than a traditional omni measurement would provide more information about the room and potentially reduce the need for additional site visits. However, using professional grade measurement equipment would be too expensive and impractical. This project provided the impetus to investigate the use of semi-professional and consumer equipment as part of a measurement system.

2 ADVANCES IN AVAILABLE TECHNOLOGY

This section outlines the advances in technology and its availability to the consumer and semi-professional market that have been beneficial in development of a low cost measurement system:

2.1 Widespread adoption of ambisonic format

As Virtual Reality (VR) and other mixed reality technology have become more common, ambisonic audio has become the standard format for sound within mixed reality content. This has meant that ambisonics equipment that was once only produced in small quantities for a specialist niche market is now being produced for the mainstream professional and semi-professional market. Ambisonic microphones are being produced by large manufacturers such as Sennheiser, Zoom and Rode. Interfaces are being produced that have 'ambisonics mode' or similar than ensures all gains are set equally. Some interfaces now include A-format to B-format conversion to simplify the user experience. Combined microphone and interface units are also becoming common with units available from Zylia, Zoom, MinDSP and Voyage Audio.

2.2 Small portable loudspeakers

Loudspeaker and battery technology has also significantly improved recently. Small portable "Bluetooth speakers" have become very common. The audio quality of such speakers vary considerably but the higher quality models produce a relatively balanced frequency response with an impressive sound output. Such speakers are battery powered and can operate for hours between charges. These loudspeaker systems are generally not designed for traditional stereo listening. Rather they are designed provide a wide distribution of sound from a single point. This 'omni-directionality' is an advantage for acoustic measurements.

2.3 Widespread adoption of ambisonic format

Wireless transmission of audio is common in the live music and broadcast sectors but has not commonly been used for acoustic measurements. High quality lossless transmitters and receivers are available, however their typical cost and complexity means they are often not practical for acoustics use. There are further complexities if signals must be accurately time aligned, as is the case with ambisonic microphone signals. Consumer grade wireless audio-over-Bluetooth devices have also significantly increased in popularity. However, Bluetooth systems are typically designed for only short range (<10 m) and the processing introduced to reduce bandwidth and latency results in an appreciable reduction in audio quality.
The increasing popularity of video recording for on-line content however has seen the introduction of low cost wireless systems for the semi-professional market that utilize 2.4 GHz transmission with minimal audio quality reduction.

3 COMPONENTS OF A LOW COST 3DRIR SYSTEM

Using the new technology available, as discussed in section 2, the following system was trialled.

3.1 Microphone and audio interface

The Zoom H3-VR is a semi-professional grade unit that includes both a tetrahedral mic array and USB interface with in-built A-format to B-format conversion. Designed to capture ambisonic audio in conjunction with a 360 camera it offers a significant number of features (Zoom, 2018) at a very affordable price (approximately $500 NZD).

Source (Zoomcorp.com)
Figure 1: Zoom H3-VR

3.2 Loudspeaker

The Bose Revolve+ is an example of high quality consumer grade ‘Bluetooth speaker’. This unit uses a single full range driver that is facing down and dual passive radiators (bose.co.nz). The sides of the unit are perforated to enable the sound to radiate in all directions. This design creates a very uniform distribution of sound in horizontal plane. The small size of the unit (18.4 cm H x 10.5 cm W x 10.5 cm D) also enables relatively uniform distribution in the vertical plane. The battery life is up to 16 hours (Bose.co.nz).

Source (Bose, 2021)
Figure 2: Bose Revolve+

Source (Bose, 2021)
Figure 3: Revolve+ loudspeaker internal cut-away

3.3 Wireless system

The Rode Wireless Go ($329 NZD) was chosen to enable wireless transmission. This system uses the 2.4 G Hz band to transmit “broadcast grade audio”(Rode, 2021) with a range of up to 70 m.

Source (Rode, 2021)
Figure 4: Rode Wireless Go

4 PERFORMANCE TESTING

Testing of the individual components and overall system were undertaken as outlined below. The purpose of these tests was not to provide comprehensive performance data but to confirm the potential suitability of the equipment for practical use.

4.1 Directional accuracy of microphone and audio interface

Impulse response measurements were made over 360 degrees at 15 degree intervals in the anechoic chamber at the University of Auckland. There was some equipment in the chamber when the tests were undertaken but this is not expected to significantly affect results.

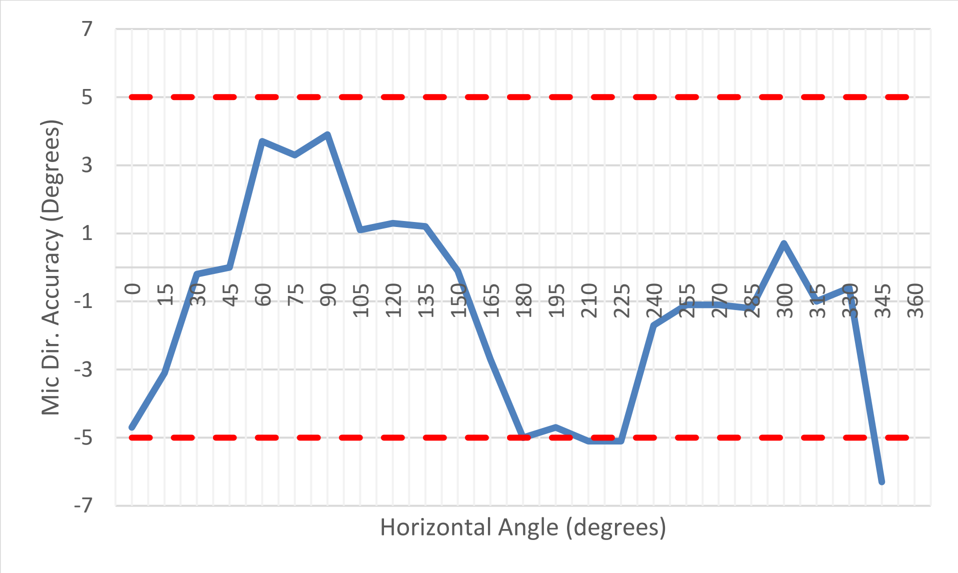

Figure 5: Directional accuracy of the system

The results show an accuracy of approximately +/- 5 degrees. This is similar to what is achieved with a fully calibrated professional grade system (Protheroe, Guillemin, 2013). Overall this indicates that the microphone capsules and preamplifiers in the interface are sufficiently well balanced and conversion to B-format provided by the H3-VR is effective.

4.2 Sound radiation of the loudspeaker

Pink noise was played through the Bose Revolve+ loudspeaker and the sound levels were measured at 30 degree intervals within the University of Auckland anechoic chamber. The speaker was The results below show the variation in level with direction both horizontally and vertically. The level is compared to information from the data sheet of a standard measurement dodecahedron which conforms to ISO 3382-1 (Lange, 2013). Overall the Bose speaker performs well and the variation with direction is similar to a standard measurement speaker in the horizontal plane for all frequencies. In the vertical plane, the variation at high frequencies is slightly greater than a more spherical speaker but the tests indicate the variation is still within suitable tolerance.

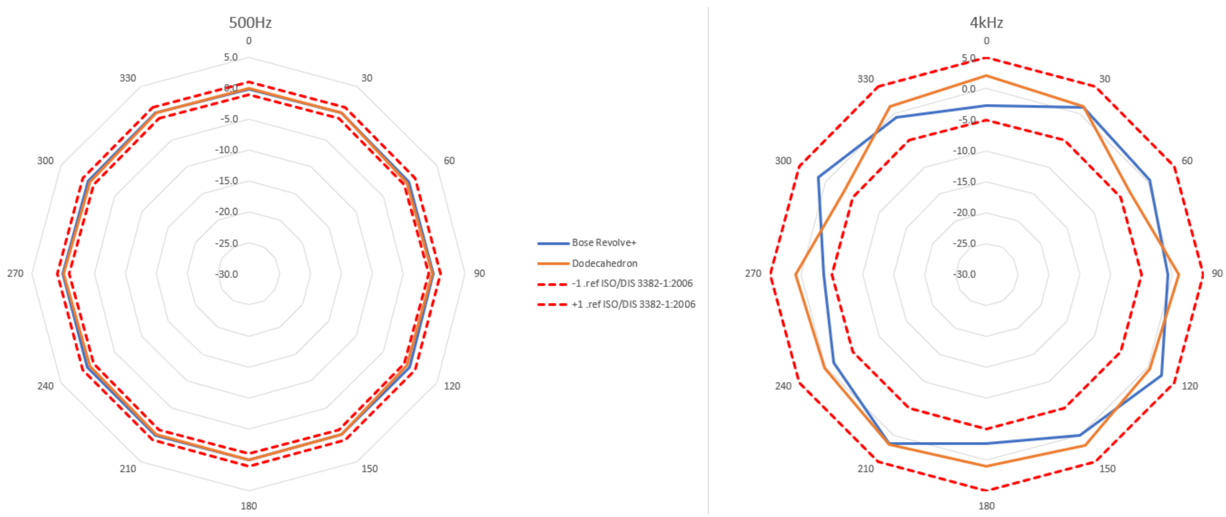

Figure 6 and Figure 7: 500 Hz and 4kHz horrizontal radiation of the Bose Revolve+

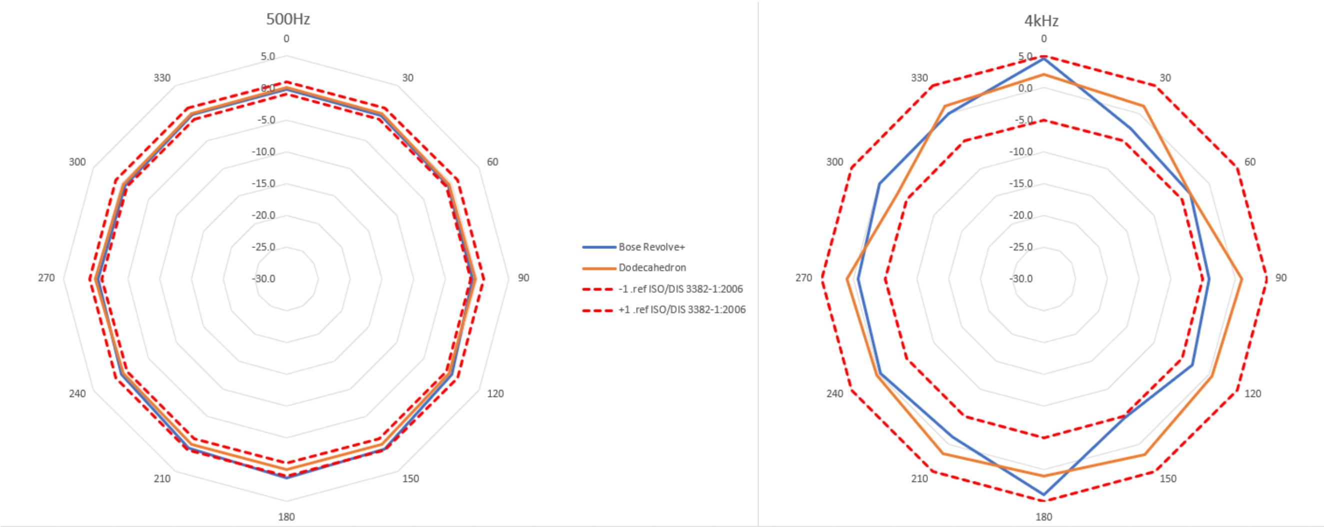

Figure 7 and Figure 8: 500 Hz and 4 kHz vertical radiation of the Bose Revolve+

4.3 Overall frequency response

The Rode Wireless Go system does not provide a flat frequency response (Rode, 2021). The system includes a high pass filter that that is, according to communication with Rode, "voiced for use with the Lav GO and a human voice". This filtering cannot be prevented. The attenuation at low frequncies unnecessarily limits the low frequency performance of the system and other wireless systems are being investigated.

However, as shown Fig 9, the overall frequency response of the system, measured in the University of Auckland Anechoic chamber, is still relatively good and the performance is relatively flat over the key measurement range of 125 Hz to 4 kHz.

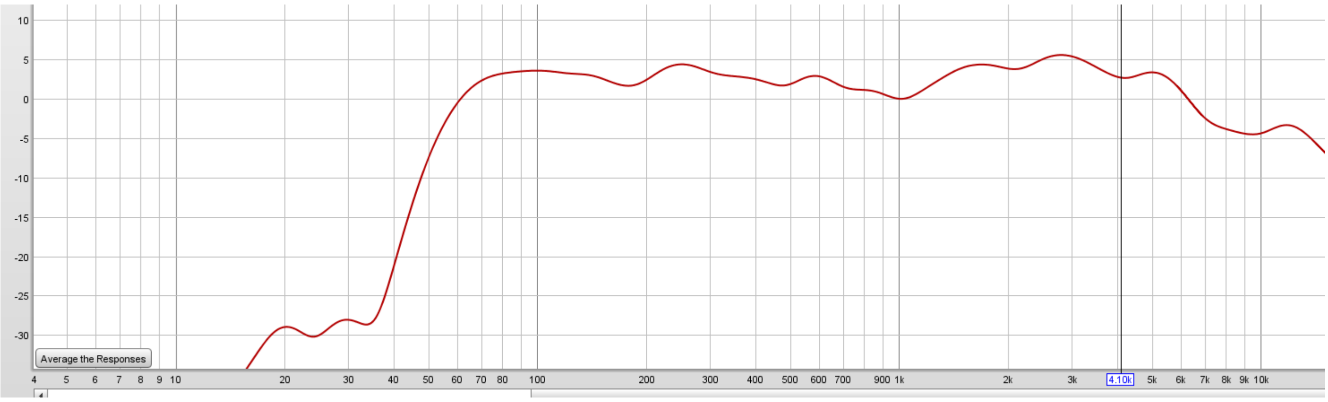

Figure 9: Frequency response of overall system (1/3 octave smoothed)

4.4 Practical Testing

Commissioning measurement were recently undertaken in a 900 seat performing arts auditorium. Measurements were undertaken using the standard Iris system and the trial system outlined in this paper.

Figure 10: System in use at a performing arts audidorium

This room was chosen to test the the ability of the system to provide sufficient excitation level in a large space and to confirm the wireless audio provided adequate transmission over extended distances.

Overall the trial system performed very well. The decay range was well above the recommend 45 dB in all octave bands from 250 Hz – 8 kHz.. The decay range was between 40 - 45 dB at 125 Hz in the most distant positions. The wireless audio link was effective even at positions at the rear of the auditorium (approx. 25 m).

The noise levels in the auditorium were relatively low (NC 25). The decay range would be lower in a similar sized room with higher background noise levels. However, the test indicated that the excitation signal would be loud enough to excite a wide variety of real spaces.

5 CONCLUSIONS

Following the body of the paper, a small and portable room acoustic measurement system has been put together from readily available consumer and semi-professional equipment.
The system enables 3D room acoustic measurement to be made more quickly and less expensively that traditional systems.
The equipment has not yet been tested for compliance with ISO standards. However initial tests and measurements indicate that the system provides comparable results to compliant systems.

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