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Application of acoustic cameras to measurement and tuning of an orchestra rehearsal room

Derek THOMPSON[1]; Lily HARKOM[2]

[1, 2] WSP, Australia

ABSTRACT

An existing rehearsal studio located in central Melbourne, Australia has been recently refitted as a temporary home for Orchestra Victoria. Following the modest refit, a process of room tuning was embarked on by the orchestra to investigate possible seating layouts within the room. Acoustic measurements were conducted at the same time to inform proposed adjustments to available room elements, and particularly an array of overhead reflector panels. The use of beam-forming microphone arrays, or 'acoustic cameras' was trialed to gather data on room acoustic conditions in the space. Measurements were conducted with both 2D and 3D cameras. In addition to the use of an omnidirectional loudspeaker source to excite the room, a handheld acoustic camera was used during live orchestra rehearsals to investigate early reflections within the room including reflectors. The process of data capture and analysis is described, along with general observations and some practical limitations observed during the process, using currently available commercial technology.

Keywords: Room Acoustics, Ensemble Conditions, Acoustic Camera

1. INTRODUCTION

Beam-forming microphone arrays, or 'acoustic cameras', have been commercially available for close to two decades now, and over that time, have found various applications especially in industrial and mining fields, as well as research and design fields such as in the automotive industry (1, 2). Through visualisation of sound level contours over a photo of the scene, acoustic cameras are typically used for the identification of noise sources, or for angular discrimination of multiple sources within a complex sound scene. The application of acoustic cameras to room acoustics has also been explored since at least 2008 (3).

However, the significant physical size of acoustic cameras (some models measure over 3 m across when deployed), and their relatively high cost has been a hurdle to widespread uptake within the acoustic consulting community. Acoustic consultants typically rely on compact, single-microphone sound level meters (SLMs) for common field surveys and internal building or room acoustic measurements.

Recent advances in microphone technology, especially application of micro-electromechanical system (MEMS) microphones is contributing to a reduction in size and cost of hardware. New products are entering the market that offer possibilities for wider application. Manufacturers are also expanding the capability of accompanying software tools, including the calculation of standardised room acoustic parameters. Despite these advances, acoustic cameras appear to be used only infrequently in room acoustic applications, and to our knowledge have not previously been used for room acoustic measurements in an Australasian context.

This paper covers an exploration of using acoustic cameras for room acoustic measurements in an orchestral rehearsal studio. Acoustic cameras were used on two different occasions, with one following 'traditional' room acoustic measurement procedures using an omnidirectional loudspeaker as sound source, and another set of measurements completed with the orchestra rehearsing to trial different seating layouts within their studio. The existing room, and variety of acoustic measurements completed are described, alongside observations of the process and some practical limitations.

[1] derek.thompson@wsp.com

[2] lily.harkom@wsp.com

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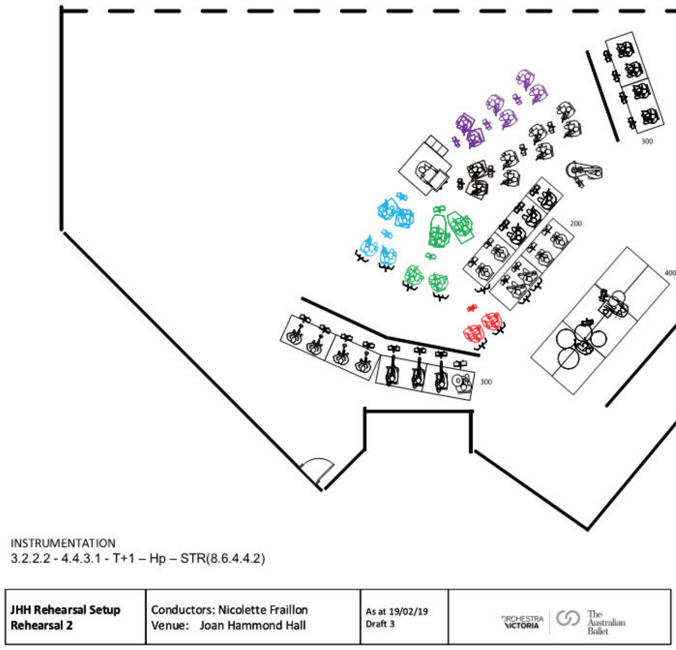
2. THE ROOM

Joan Hammond Hall is a rehearsal studio in Melbourne, Australia. Originally built as a rehearsal studio in the early 1990s, the space had been altered and then used for commercial offices and storage for over a decade. In 2018 it was reclaimed as a rehearsal studio and home for Orchestra Victoria. To accommodate the orchestra, the space has undergone a basic refit on a limited budget. The refurbishment of the studio was intended to provide the orchestra with an adequate temporary home, only until a permanent facility can be developed.

The rehearsal room itself is irregularly shaped, has approximately 500 m^2 floor area, and at just under 7.5 m height encloses a room volume of almost 3750 m^3. Wall surfaces are generally framed plasterboard, with convoluted polyurethane foam absorption at high level, and fabric-faced fibrous absorption panels fitted to parallel opposing walls at lower level. These acoustic treatments were existing, and although the materials appear to be towards the end of their expected life, they were retained for the recent refurbishment. A sprung timber floor has been installed to enable dance rehearsals, and additional acoustic treatments have been installed consisting of sound-absorbing drapes suspended below the soffit at a high level, perforated timber-faced panels to lower walls, and an array of simple plywood reflectors suspended overhead. The mid-frequency reverberation time in the studio is 1.0 seconds (unoccupied).

3. USING THE ORCHESTRA AS SOUND SOURCE

When investigating a music rehearsal space, especially where time and budget are limited, a typical acoustic process may involve attending scheduled rehearsals to hear the ensemble rehearsing under normal conditions, and then conducting room acoustic measurements using a loudspeaker in an unoccupied space (e.g. using impulse response analysis derived from swept-sine recordings). Whilst relatively straightforward and repeatable, the process of capturing impulse responses using an omnidirectional loudspeaker and microphone pair in an empty room, cannot capture many subtle acoustic features such as the distribution of instruments, tonal character and directivity of individual instruments, or distribution of room absorption, reflective or diffusive elements.



	Rostra	Screens
Setup 1	Yes	Yes
Setup 2	Yes	No
Setup 3	No	No
Setup 4	No	Yes

Figure 1 – Sketch layout for a possible orchestra configuration (supplied)

In this case, we had an orchestra willing to explore different layout options within the existing room through a set of dedicated rehearsals, and so we sought to make the most of the orchestra itself as an acoustic test source. We were particularly interested in the efficacy of overhead reflectors (one of the few room elements available to us for adjustment), and their influence on ensemble conditions for the conductor, and for the different sectional groups. For this purpose, a relatively new tool in the acoustic consultants' arsenal – a handheld acoustic camera – offered good potential for unobtrusive use in and around a live orchestra, and the opportunity to focus on specific details such as overhead reflectors. We had prior experience using large acoustic camera arrays for investigation of industrial noise sources, but the possibilities of using this technology in a smaller physical format, and application of this to an investigation of room acoustics in a rehearsal space was new to us.

3.1 The orchestra

Orchestra Victoria is a partner to the Australian Ballet and Opera Australia, and so perform primarily as a pit orchestra. However, the orchestra do conduct their own chamber music and orchestral concert series', occasional educational workshops, and public concerts in their rehearsal studio. This breadth of programming demands a variety of ensemble sizes between rehearsals, and the potential for exploring different seating arrangements within their present rehearsal space.

3.2 Musical excerpts

The orchestra arranged for a series of rehearsals over two days, dedicated to auditioning the room in different configurations. Two short musical excerpts, already well known to the orchestra were selected for playing, each approximately six minutes in length and selected by the Music Director and Conductor to showcase different sections of the orchestra, and variety of ensemble scoring. A moderate size ensemble was used for these rehearsals, slightly smaller than a full orchestra call, but still including a full complement of orchestral sections, including percussion (Figure 2).

Figure 2 – Scoring for the music used from *The Barber of Seville* (4) and *Swan Lake* (5)

4. MEASUREMENTS

As the application of acoustic camera technology to room acoustics or a rehearsal room setting was unproven for us, we supplemented the handheld acoustic camera data obtained during live rehearsals with follow-up measurements when the space was empty. The follow-up measurements made use of a larger spherical array acoustic camera and 3D scanner, as well as a SLM.

These measurements were made immediately before and after adjustments to overhead reflector elements, allowing us to capture room data for two different room conditions and allowing us to compare acoustic camera data around known changes to the room.

4.1 Sound level meter

A Type-1 SLM (*NTi XL2*) was used to acquire baseline acoustic parameters, including sound levels during the orchestral rehearsal sessions. During later measurements, a series of reverberation time measurements were also made using the interrupted pink noise method. This type of SLM is familiar to acoustic consultants, and capable of quickly capturing general indicators of room acoustic conditions such as ambient noise levels and reverberation time. However, as a single-channel omni-directional measurement tool, it is inherently limited to assessing the overall sound field at a single location per measurement. There is no ability to discriminate directivity in the sound field. To consider angle of incidence and distribution of the sound field, two different acoustic cameras were also employed.

4.2 Handheld acoustic camera

For the orchestra rehearsals, a 2D acoustic camera (*gfai tech Mikado*) was used (Figure 3). This product is a relatively new product, having only been on the market since 2018. The array consists of 96 MEMS microphones, measures 450 mm across, and is powered from an interchangeable power-tool type battery integrated into the unit's base. The unit connects directly to a tablet computer allowing data review and a basic level of post-processing for analysis to be conducted onsite. It is feasible to use the unit as a handheld device, however with the tablet attached it weighs in at over 3 kg, so we opted to mount it on a tripod for stability and repeatability of measurement positions, and to avoid potential muscle strain over two long days of use.

Figure 3 – Measurements with 'handheld' acoustic camera amongst the orchestra

It is only slightly larger than a typical SLM and so could be readily moved around the room to capture data from different angles relatively quickly.

4.3 Spherical acoustic camera

We had access to a larger 3D, spherical array acoustic camera (*gfai tech Sphere48)* for the follow-up acoustic measurements during adjustment of reflector panels (Figure 4. These measurements were made with the room unoccupied, ,so allowing greater flexibility for positioning of the acoustic camera, but requiring a loudspeaker sound source in lieu of an orchestra.

Figure 4: Measurements with a 3D acoustic camera and omnidirectional loudspeaker

4.4 3D scanner

A 3D laser scanner (*Faro Focus3D X130*) was used to capture detailed data on the room geometry. Conducting 3D scans of the room provided two major advantages for the orchestra studio – enabling data captured with the 3D camera to be overlaid on detailed 3D models of the room, and documentation of changes to the room. Such documentation was especially attractive for this space, as we had been unable to otherwise source accurate drawings or 3D models of the existing space. By using a 3D scanner, a detailed and accurate record of all room elements could be captured quickly, including any changes to the height and angle of overhead reflectors. If further works are proposed in the future, we also now have a reliable baseline model available on which to build acoustic modelling for ray-tracing calculations.

5. ROOM ADJUSTMENTS

Following the initial investigations with handheld acoustic camera while the orchestra was playing, a series of potential room adjustments were determined. In practice, immediate changes were limited to adjusting the height and angle of the overhead reflector panels. The panels are a simple flat plywood sheet, suspended by adjustable steel cables from the soffit, in an approximate chequerboard pattern. The panels had been installed around building services, and initially set at a convenient height to avoid conflict with existing suspended items such as lights and curtain tracks.

Adjustments to the panels were determined through a combination of interrogating the acoustic camera data; considering first-order reflections relative to preferred seating layouts (indicated by the musicians); and allowing for built constraints such as length of hanging cable available for adjustment. Individual reflectors panels were lowered between approximately 800 and 1 500 mm, and each panel was angled, varying from flat to approximately 10 degrees inclination.

Further room adjustments may be considered later, subject to available budget and the time the orchestra are likely to remain in the studio as a temporary home.

6. DATA VISUALISATION

Data collection using the acoustic cameras was a relatively simple process. However, for the uninitiated, post-processing of the data can easily consume more time than expected. A combination of sheer volume of captured data, individual files sizes, and modest laptop specifications resulted in processing the available data within a reasonable timeframe. Greater familiarity with the analysis software, combined with a more targeted data capture regime would go some way to reducing the time cost of processing acoustic camera data.

Data processing times for 2D images from the handheld unit were generally manageable with a reduced frequency range and/or limited time-period. However, processing a full-frequency movie file with 3D mapping from a measurement only 30 seconds in length, could take more than an hour to process. Some example outputs of data visualization are shown in the figures below.

Figure 5 shows a full-bandwidth spectrogram processed for a 16 second portion of a musical excerpt with orchestra playing. The localisation of sound to individual instruments can be clearly seen, as can key reflections (e.g. floor reflection in front of cello).

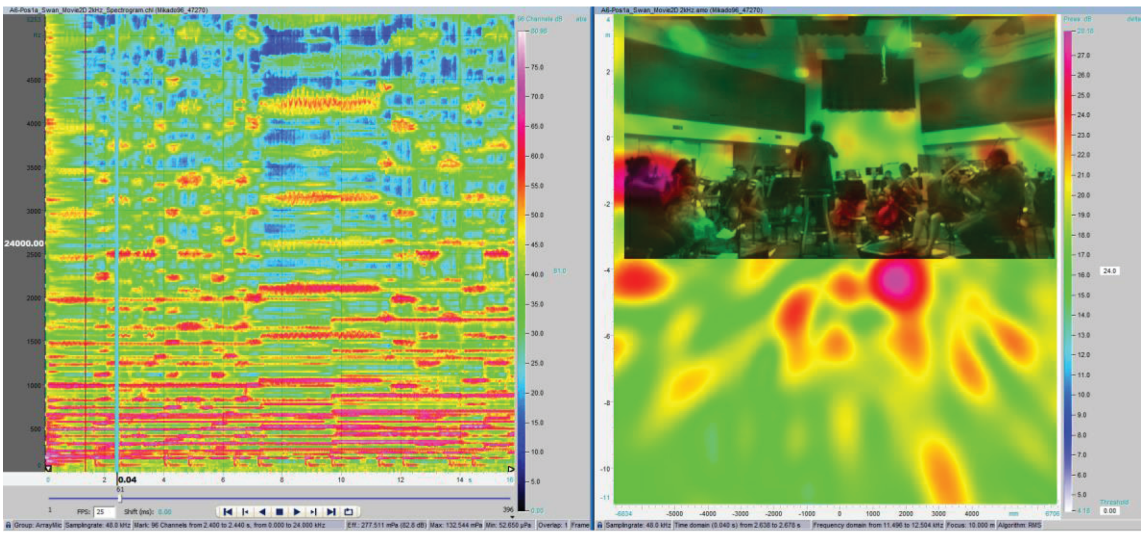


Figure 5: Example 2D sound map, showing spectrogram (left) and level map (right)

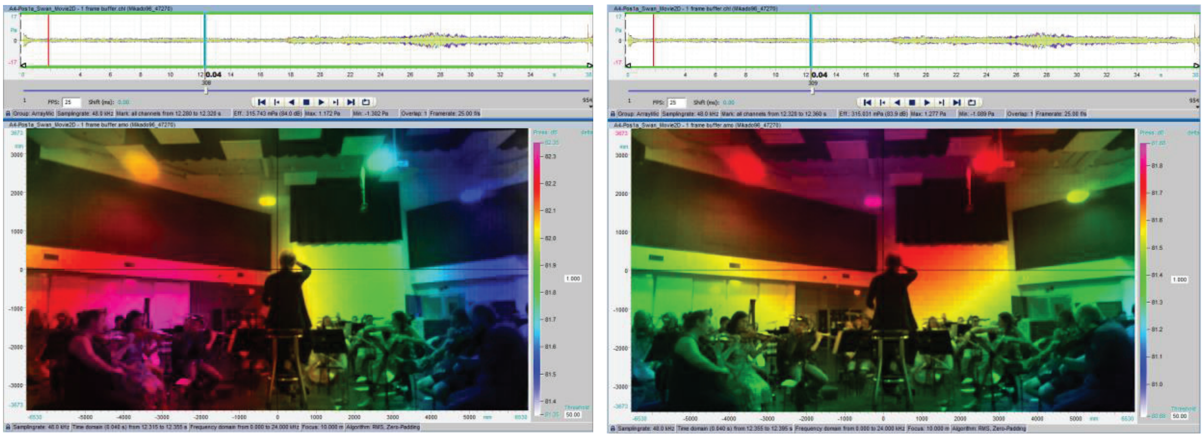


Figure 6: 2D sound map showing a violin note dominating (left), and room response one frame later (right)

Figure 7 shows a 3D sound map taken after adjustment of reflectors, using the omnidirectional loudspeaker as sound source. The sound map here is displaying part of an impulse response, projected onto the 3D laser scan of the room.

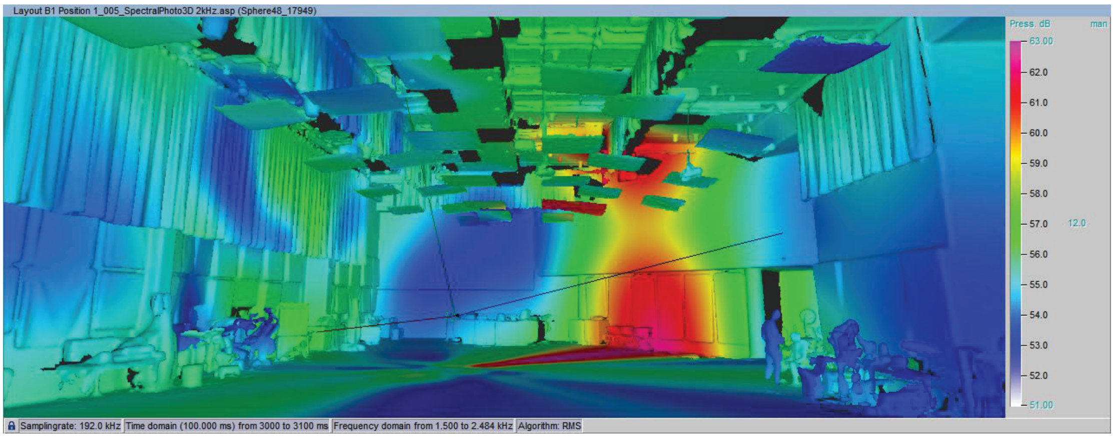


Figure 7: 3D sound map projected onto a 3D scan of the room

7. PRACTICAL LIMITATIONS

Beyond actual computer processing time to produce graphical outputs, several limitations and constraints were identified in the data capture process.

7.1 Frequency response

A potential constraint is the inherent limitation of smaller diameter microphone arrays, as the physical size controls the lower frequency limit for accurate localisation. The manufacturer's recommended lower limit for localization is around 500 Hz for the 2D acoustic camera (6), and 400 Hz for the 3D acoustic camera (7).

The quoted cut-off frequencies were below the frequency range of interest for investigating suspended reflectors and articulation of the violin and woodwind sections of the orchestra, so did not present a practical constraint for this investigation. It is conceivable however that larger microphone arrays may need to be considered if investigating low frequency phenomena or room conditions specific to bass instruments (e.g. tuba, double-bass).

7.2 Viewing angle and measurement distance

. The viewing angle of the fixed focus video camera on each device is narrower than the angle of incidence that each microphone array can resolve – especially for the spherical array. In practice the integrated camera is most useful for aligning the orientation of the unit when loading a 3D cad model or laser scan of the room into the analysis software for post-processing.

Nevertheless, the handheld unit with tablet computer has an advantage of displaying a basic directional sound map in real time, allowing the unit to be quickly reoriented within a room to investigate specific room surfaces.

A potential constraint is the manufacturer's recommended measuring distance (0.3 – 5 m). This relates mainly to the video camera resolution and viewing angle, as a suggested range to ensure acceptable visual detail is available in the base imagery that the sound field is being mapped to. This is less relevant where a 3D model or scan is loaded into the analysis software, although it should still be noted that any output mapping is limited by the angular resolution (with frequency) of the acoustic camera. For the scale of room surfaces in the rehearsal studio under investigation, the angular resolution was quite adequate to identify orchestral sections and relevant reflecting surfaces.

7.3 Data size

Data collection with the acoustic cameras revealed a two-fold challenge: the time-period of data capture possible for individual measurements is limited; and the cumulative size of data files collected quickly becomes substantial.

Using the handheld acoustic camera, we were limited to individual measurements of up to 38 seconds in length, at a 48 kHz sample rate. Alternative sample rates are available (up to 192 kHz), allowing some trade-off between frequency response and capture time-period. The limited capture times are quite adequate for capturing steady state or even many transient noise sources, but was a significant constraint when capturing a live orchestra. Even when using relatively short musical excerpts, the orchestra were playing for close to six-minutes at a time. Recordings that captured an entire excerpt were therefore not possible, and instead each excerpt required multiple recording captures, inevitably with portions of the music missed while data was saved and the camera reset for the subsequent recording.

Despite the limitations on time-period of individual measurements, each measurement created a data file over 1 GB in size. This is due quite simply to the number of audio channels recorded simultaneously (one per microphone) to allow full-resolution export and detailed data analysis and beam forming. Over a two-day period onsite measuring the room and orchestra in various configurations, the total raw data set amounted to approximately 100 GB . An additional day of capturing short noise bursts and swept-sine tones added another 65 GB of raw data from the spherical acoustic camera and 3D scanner.

While such data sets are generally manageable with current computing technology, some care is required if storing such file sizes on shared fileservers, or relying on typical internet connections for uploading the data to remote sites or cloud-based storage systems.

8. CONCLUSIONS

The opportunity to work closely with a professional orchestra to assist them in tuning their current rehearsal space was an invaluable exercise. It is rare that an orchestra gets to trial alternative layouts in an experimental and repeatable manner. It was a privilege to capture the acoustic implications of these experiments using current technology to provide far greater detail than previously imaginable. Being a trial process, there were various limitations and constraints discovered along the way. We now have a working appreciation of where such technology can be applied to useful effect, and where

In this trial, only the handheld acoustic camera was used during orchestra rehearsals. It would be interesting in future also to trial 3D cameras in a rehearsal setting, to capture the full-sphere directional information with the orchestra as sound source. Nevertheless, this method of data capture appears promising, and clearly offers the ability to capture far greater spatial detail than can be achieved with single-microphone SLMs.

Overall the process was found to be worthwhile, and has generated an extensive dataset useful not only for the immediate task to adjust overhead reflectors, but for other works that may become feasible in the future. We look forward to continuing to work with Orchestra Victoria and assisting them with tailoring of their rehearsal space.

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REFERENCES

1. Heilmann G, Doebler D, Boeck M. Exploring the limitations and expectations of sound source localization and visualization techniques. Proc Inter-noise 2014; 16-19 November 2014; Melbourne, Australia.

2. Doebler D, Heilmann G, Meyer A, Waibel H. Fields of application for three-dimensional microphone arrays for room acoustic purposes. Proc Acoustics 2011; 2-4 November 2011; Gold Coast, Australia.
3. O'Donovan A, Duraiswami D, Zotkin D. Imaging concert hall acoustics using visual and audio cameras. Proc ICASSP 2008; 30 March – 4 April, 2008; Las Vegas, USA. p. 5284-5287.
4. Rossini G. Overture for the opera The Barber of Seville. 1816. Pub Edwin F Kalmus & Co, Boca Raton, Florida.
5. Tchaikovsky P. Swan Lake, Op 20. 1875-77. Pub P Jurgensen, 1895. Moscow. Reprint Broude Brothers, 1951, New York.
6. Acoustic-camera.com. (2019). *Mikado - The handheld Acoustic Camera datasheet*. [online] Available at: https://www.acoustic-camera.com/en/products/microphone-arrays/mikado.html [Accessed 26 Jul. 2019].
7. Acoustic-camera.com. (2019). *Sphere 48-35 AC Pro datasheet*. [online] Available at: https://www.acoustic-camera.com/en/products/microphone-arrays/sphere-48-35-ac-pro.html [Accessed 26 Jul. 2019].