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Sound Decisions: Moving forward with Acoustics

Using acoustic cameras with 3D modelling to visualise room reflections

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ABSTRACT
Advances in beam-forming microphone array (acoustic camera) technology has made acoustic cameras more accessible for use within acoustic consultancy. Recently we had the opportunity to use acoustic cameras in conjunction with 3D room scanning to investigate acoustic conditions in an orchestra rehearsal studio. The acoustic camera data was used to assist in visualising the frequency response, reflection patterns and overall reverberant response within the room and as an aid for tuning room elements such as ceiling reflector panels. This paper describes the process of using acoustic cameras in conjunction with 3D room scanning and CAD modelling to visualise room reflections for acoustic analysis. It will also discuss the potential of related technology, such as the use of 3D modelling and the potential for interactive visualisations using virtual reality (VR) tools.

1 INTRODUCTION
Traditionally measurements used to analyse the response of sound within a space are conducted with a single microphone sound level meter using methods such as those outlined in ISO3382-1. This generally gives sufficient information to assess the overall acoustic conditions within a space, but typically assumes time invariance, and provides only limited insights to the directional distribution of sound, or the change in directional sound over time.

Recent advances in technology are enabling new insights into the directionality. An example is beam-forming microphone arrays, otherwise known as acoustic cameras. Historically these acoustic cameras have been used in the mining, industrial and automotive industries (Heilmann et al, 2014; Doebler et al, 2011). Limitations in microphone technology generally meant that the size of acoustic cameras were quite large and costly and this has been a factor limiting adoption of this technology into broader consultancy practice.

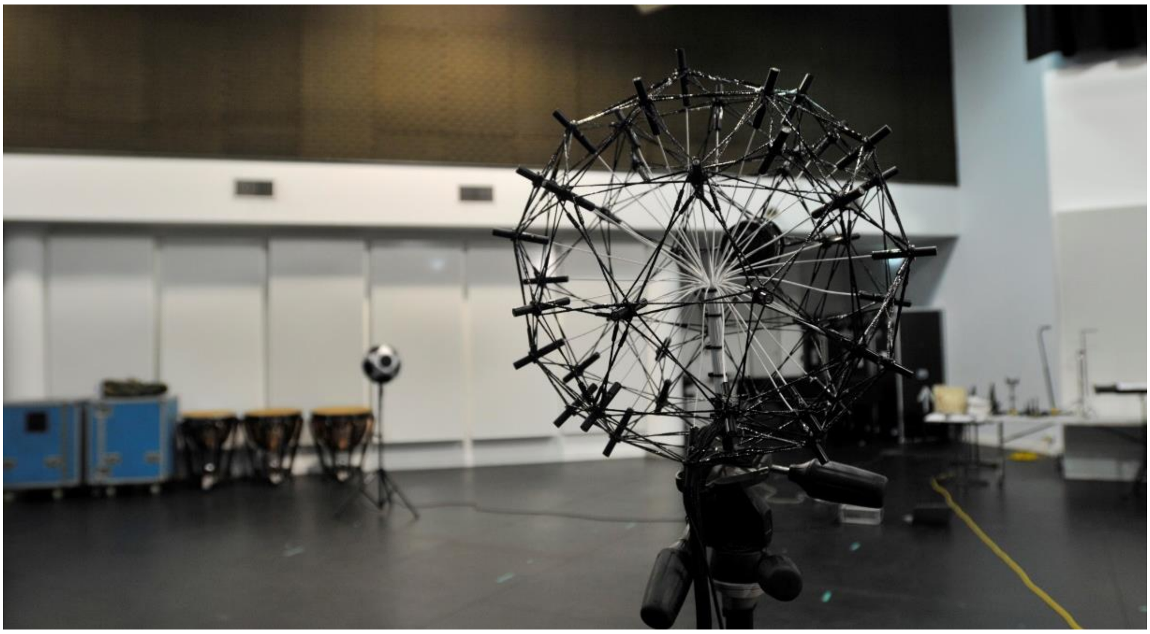
This paper describes the process of using acoustic cameras in a room acoustic application, with 3D modelling software to visualise room reflections. It discusses the equipment used, the measurement approach, 3D scanning to model conversion, various methods available for data visualisation and some further applications such as presenting data within virtual reality (VR) environments.

2 MEASUREMENTS
The main objective for taking measurements within the orchestra rehearsal space was to support tuning of a limited number of room for suspended ceiling reflector panels. To aid in the process of tuning these panels, various measurements were taken both with and without the orchestra present, outlined below. A more detailed description of the measurements and practical limitations found during the process has been presented previously (Thompson and Harkom, 2019).

2.1 Acoustic Cameras
The first of these measurements were taken with a 2D hand held acoustic camera (*gfai tech Mikado*) mounted to a tripod during live orchestra rehearsals using the orchestra as the sound source (Figure 1). This camera is relatively new, light weight (around 3 kilos) and it's portability was useful in taking measurements of the live orchestra, which involved moving the camera to various locations while the orchestra was playing. Measurements were triggered from and saved to an attached tablet running proprietary software (*NoiseImage 4.0 gfai)*.

Source (Author, 2019)
Figure 1: Hand held acoustic camera mounted to tripod during a rehearsal

The second set of measurements were taken in an unoccupied room, before and after ceiling reflector panel adjustments These measurements were focused on determining room impulse responses, and were made using a spherical acoustic camera (*gfai tech Sphere48)* and omnidirectional speaker (*Brüel & Kjær Type 4292*) to generate swept-sine signal or broadband pink noise as test sound sources (Figure 2).



Source (Author, 2019)
Figure 2: Spherical acoustic camera (front) with omnidirectional speaker (back)

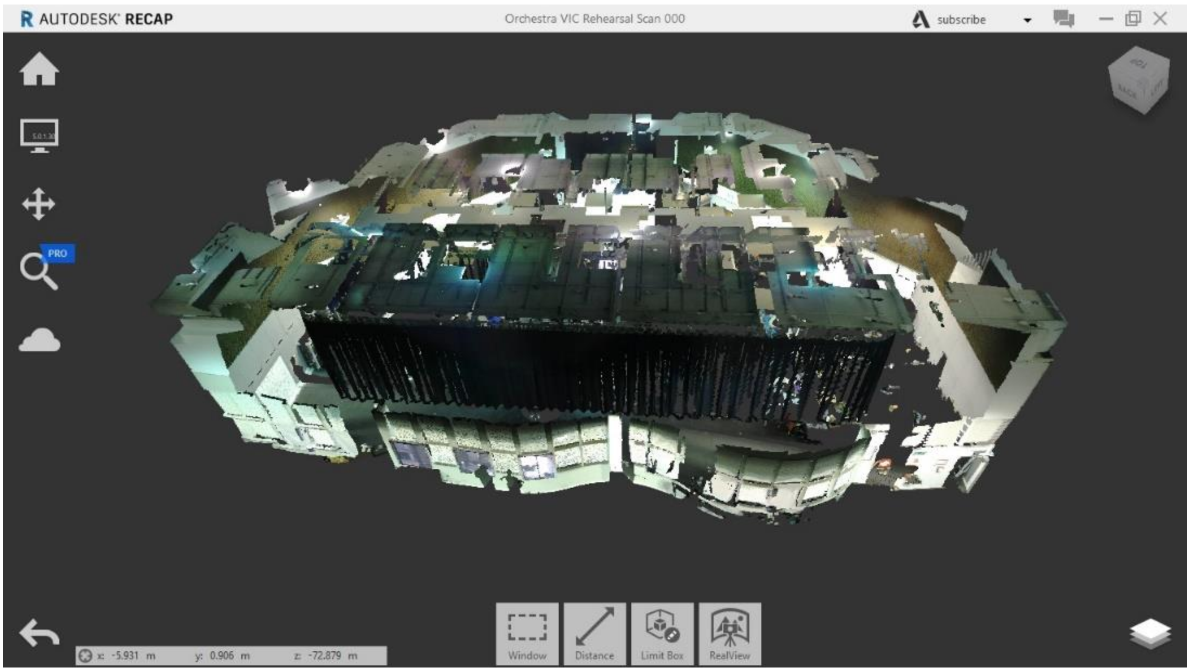
2.2 3D Scanner

During the different measurement stages, a 3D room scanner (*Faro Focus3D X130)* was used to map the space (Figure 3). This was used as a record of different setups (orchestra orientation, screens, rostra), as well as to measure detailed location of movable room elements such has suspended reflector panels. The intention was to derive point cloud renders of the spaces to be used for 3D modelling purposes, both with the proprietary software and with simplified CAD models for further exploration of different presentation technologies including VR.

Source (Author, 2019)
Figure 3: 3D Laser Scanner

3 3D ROOM MODELLING

In simple terms, 3D laser scanners create a 3D replication of spaces by recording a set of points in space generated by shining a laser beam on a surface and recording the distance to the point. This ‘dot-cloud’ survey is supplmented in many scanners with a camera to provide a photogrammetric representation (Figure 4). The number of points and angular resolution of a dot-cloud survey can typically be varied to suit the size and complexity of the space being surveyed.

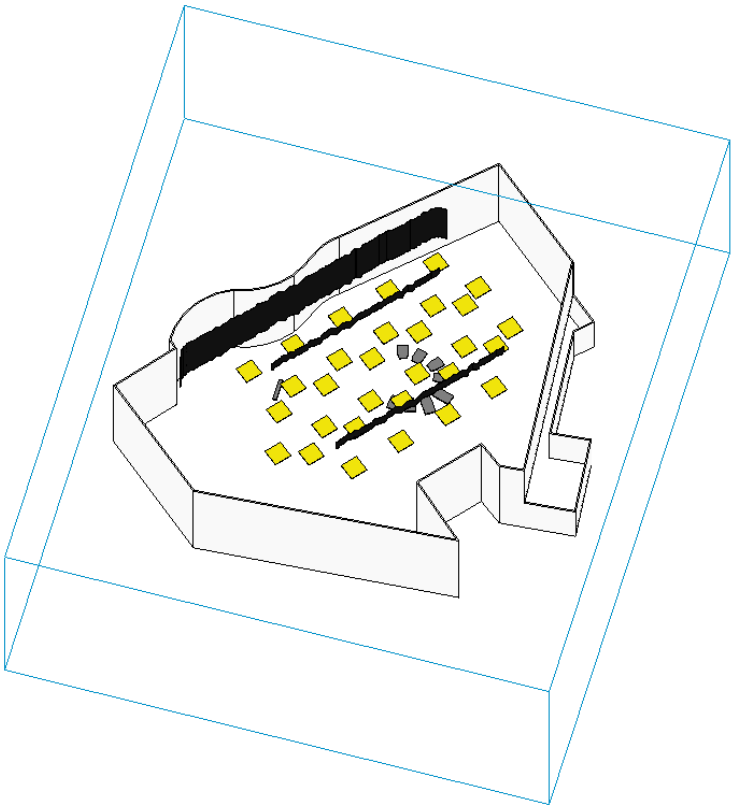


Source (Author, 2019)
Figure 4: Laser scan with photogrammetry displayed in ReCap software

3.1 Simplified 3D CAD Model

The process of taking the 3D laser room scans and converting them to a useable CAD required a few steps. Initially the room scans came in a format not recognised natively by the CAD software in use (*Autodesk Revit*). In order to bring the scans into the CAD software, they needed to be indexed then converted to a format that could be more readily used. In this case the indexing and converting was done using *Autodesk ReCap*.

Once the dot-cloud survey (also known as a point cloud within the CAD software) had been indexed, it was then inserted into a CAD project as a whole object. This could either be viewed and used as a base directly, or for practical manipulation and viewing could be simplified. Simplifying the model involved tracing the relevant elements using the point cloud as the reference. Once this process was complete the point cloud was removed, leaving a simplified 3D model of the room (Figure 5).

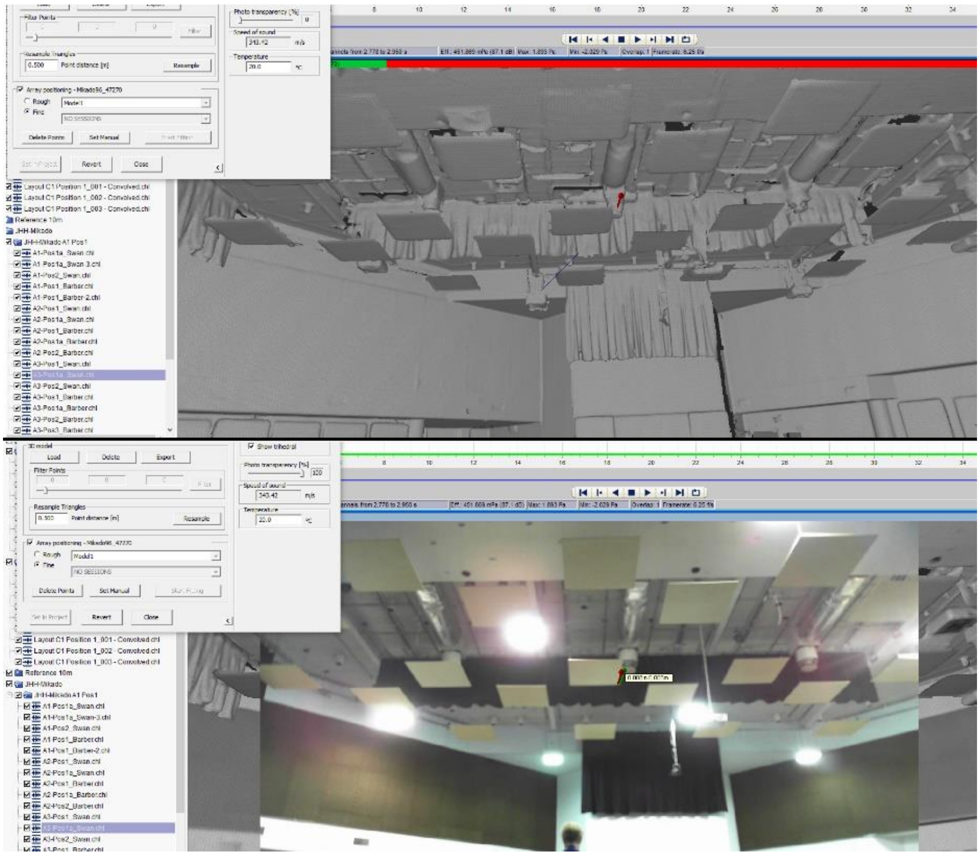


Source (Author, 2019)
Figure 5: An example of simplified CAD model reduced from a dot-cloud survey

3.2 Acoustic Camera Proprietary Software 3D model

The process for taking the 3D laser scans and importing them into the acoustic camera analysis software involved a different process. The model itself could be loaded into the software directly without indexing or conversion, however due to the number of points in the dot-cloud survey the imported model was very complex. The software allowed for a reduction in the number of points used which simplified the model. Once the model was inserted, it needed to be aligned to an image taken by acoustic camera through a process of selecting x, y, z co-ordinate points on the dot-cloud survey, and matching them to corresponding x, y, z points from the acoustic camera video image through a manual visual comparison process (Figure 6).

Once the model was aligned to the acoustic camera image, then the camera data was able to be overlayed on the room surfaces for visualisation within the 3D model.



Source (Author, 2019)

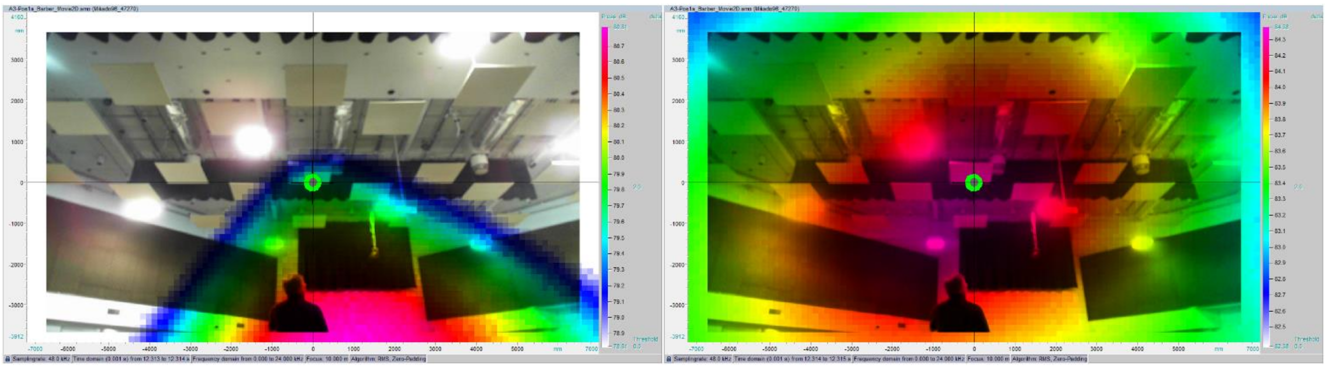
Figure 6: Aligning co-ordinates for dot-cloud survey (top) with acoustic camera image (bottom)

4 ACOUSTIC CAMERA DATA VISUALISATIONS

Acoustic cameras use differential beam forming algorithms to analyse the directionality of incident sound (Kümmritz and Kerscher, 2019). There are many different ways the data analysis can be represented using the proprietary software. The volume of data available and the different ways available to present the information provided numerous opportunities for analysis and data visualisation. The challenge in many applications may be in electing the most meaningful presentation method and to process the relevant data in a timely manner, as this process was potentially found to be quite involved.

4.1 2D vs 3D visualisation

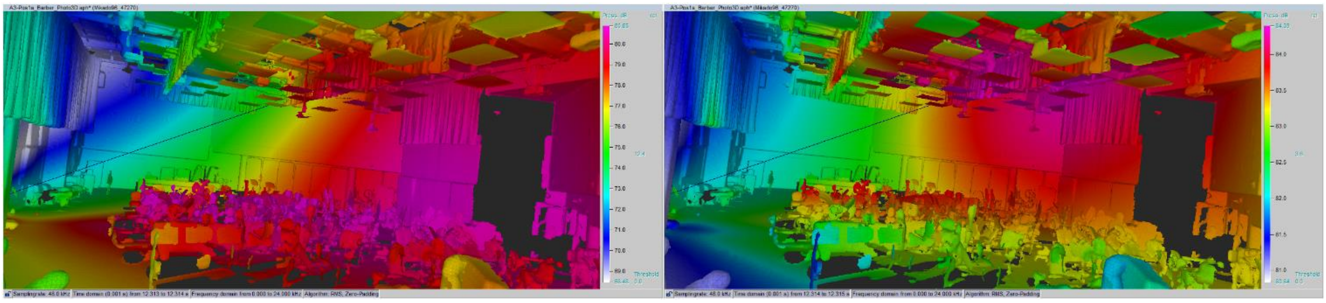
The sound pressure levels (SPL) of both direct and reverberant sound can be presented as a heat map over either a 2D movie, or the 3D model. In the case of the 2D movie, this proved useful for identifying sound sources and to trace early reflections (Figure 7).



Source (Author, 2019)

Figure 7: 2D movie frames with heat map showing direct sound from orchestra (left), and 1 frame later reflected energy from reflectors and room corner (right)

The limitation of the 2D movie is the restriction of the visualisation to the camera image. The 3D model provided more information to the whole space which could be navigated through to provide a more indepth review of the room response (Figure 8).



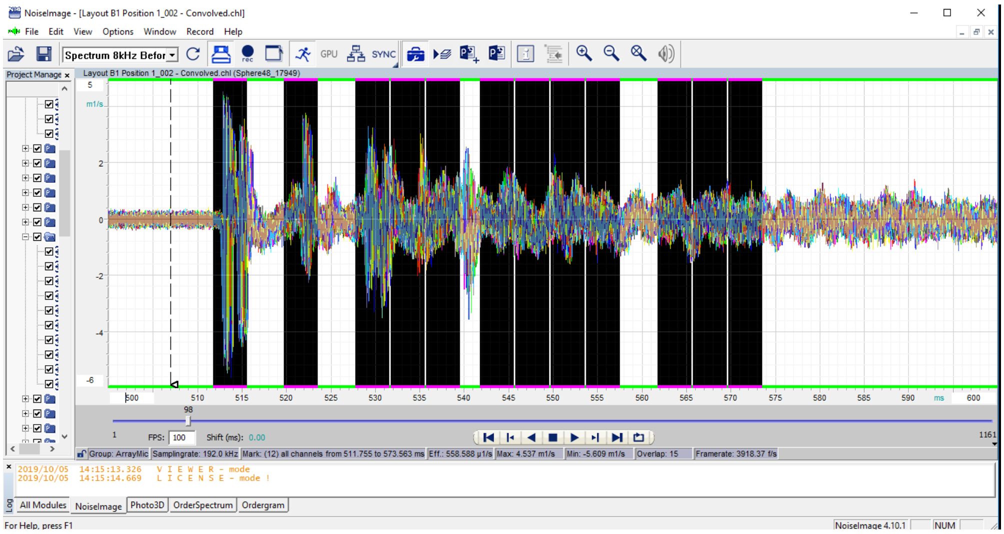
Source (Author, 2019)

Figure 8: 3D model with heat map overlaid showing sound from orchestra (left) and 1 frame later early reflections from ceiling reflectors & room corner (right)

4.2 Reflection Identification

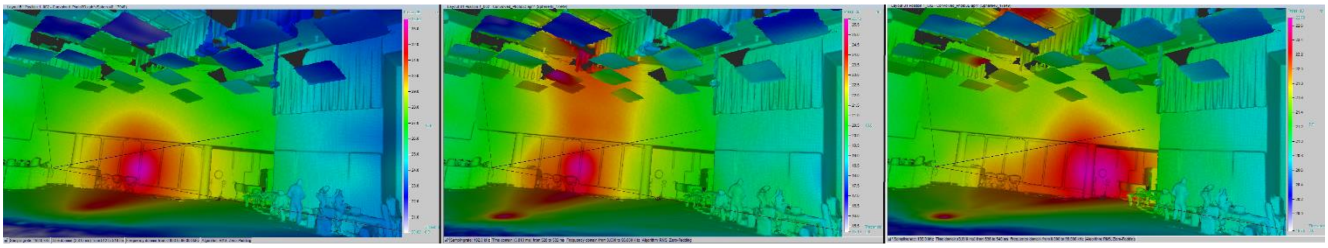
During the room tuning, a number of sine sweep measurements were made. These were processed in the analysis software with the original sine sweep file to generate room impulse responses for further analysis. One feature of the analysis software is automated reflection detection (Figure 9).

Using the reflection detection, individual reflections of interest could be quickly singled out for further anaylsis or visualisation within the 3D model (Figure 10).



Source (Author, 2019)

Figure 9: Reflection identification from impulse response



Source (Author, 2019)

Figure 10: Direct/first reflection, second and third reflections mapped to 3D model.

4.3 Room Acoustic Parameters

During the measurements, we took additional measurements with a Type 1 calibrated sound level meter to provide comparative readings. The acoustic camera analysis software includes a partial implementation of ISO3382 parameters, allowing comparison of at least basic room acoustic parameters. The readings are presented by microphone rather than an averaged result. This meant that some microphones within the spherical array didn't produce useable data, however there were enough with useable readings to take a sample and provide an average based on that sample.

5 3D MODELLING AND VIRTUAL REALITY (VR)

The use of 3D modelling by the acoustic camera software opens up the possibility of using this technology in a virtual reality environment. VRML (Virtual Reality Markup Language) files can be generated from the proprietary software showing measurement results heat mapped onto a 3D environment. VRML is considered a universal format for 3D programming and allows for the generation of 3D models that can be accessed through readily available VR hardware such as Google Cardboard, and common platforms such as HTC Vive etc.. This would enable an acoustic consultant to walk a client and their design team through a room to view the measurement results or to 'inspect' room surfaces of specific interest.

6 FINAL REMARKS

Acoustic camera technology is an established tool in many industrial noise applications. This paper explored the application of acoustic cameras to room acoustic measurements, the potential for visualisation of complex datasets, including potential for presentation using VR tools. Depending on project requirements, this approach could provide a valuable means to share work across locations through shared VR environments . Having a clear idea of the data to be extracted and how it is to be presented should be a key planning factor, as well as allowingsufficient time to address data processing.

7 ACKNOWLEDGEMENTS

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