THAT WAS GREAT, CAN YOU PLAY IT AGAIN? MAKING 3D ACOUSTIC MEASUREMENTS OF INSTRUMENTS UNDER PERFORMANCE CONDITIONS.

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1. INTRODUCTION

When a musician plays upon their instrument, they create a sound which radiates away from the instrument in all directions. Not all directions are equal, however, and the various sound components generated by the instrument will radiate in different directions, with a variation in the frequencies which are radiated in each direction (an example can be found in[1]).

Research for a number of years has been undertaken to analyse this acoustic radiation in a variety of ways, mostly by actuating the instrument artificially using electro-mechanical means[2,3,4]. This process has the advantage that the measurements are repeatable, as the actuating device will have a consistency of performance such that repeatable measurements can be made.

However, this methodology does not take into account the acoustic effects of a musician who may play the instrument, and so any acoustic radiation data gathered may not be indicative of real-world musical performance[5,6]. In order to make measurements that reflect the acoustic effects of the musician, the measurements must be made with the musician performing or sounding the instrument. This requires a different approach to the measurement as, while the radiation in various directions of mechanically actuated instruments can be measured one data point (direction) at a time due to the repeatable nature of mechanical stimulus, the real human musician will not be able to play with the consistency in dynamics and tone required for making comparable acoustic radiation measurements[7]. Thus, all data points (directions) must be measured at the same time, for example by utilising an approximately spherical grid of microphone sensors.

The work described here is a discussion of the design and initial testing of such an acoustic measurement system, consisting of a large number of microphone sensors in a polyhedral grid array surrounding the musician[6]. This system is designed to take measurements at spatially averaged points, but with a better spatial resolution than described in some of the previous literature[8]. Having data for a number of directional points around the musical instrument sound source allows interpolation of data to allow prediction of the frequency-amplitude response at any direction around the instrument. This interpolation will hold for all frequencies up to the range where the wavelength is of the order of the physical spacing between the sensors – a larger number of sensors with a smaller average distance between them will give acceptable results up to a higher frequency.

The measurement system consists of the approximately spherical grid array of microphone sensors, which are connected to a set of synchronised multi-channel analogue to digital convertors. These digitised signals are then simultaneously recorded by an array of hard disk recorders, such that the output from the instrument under test can be captured in many directions simultaneously. This data can then be processed and analysed as required.

2. SYSTEM DESIGN

Specific design challenges for the instrument included the sensor array design, optimising for best spatial coverage of the spherical area around the source, and how much of the sphere to include. It is currently thought that in order to mimic normal playing conditions, it is not necessary to cover the full lower section of the sphere with sensors (as the area there would be occupied by the normal floor space, although to retain the option to use a somewhat reflective floor (e.g. carpet on wood) with the musician at normal playing height, or a fully anechoic environment and to take measurements without floor reflections.

The microphone sensors are omnidirectional pressure microphones, and the positions has been determined as a grid pattern on a geodesic dome grid, as this appears to offer a relatively even distribution of data points on a spherical surface[9.]. For a variety of reasons, the number of sensor data points was decided at 120, as it fulfils the requirement for high spatial density[1], and corresponds to multiples of numbers of channels in the hard disk recorders and analogue to digital convertors used. This number has also been used as the number of data points/sources in synthesized acoustic radiation experiments detailed in prior spatial audio research[10].

This number of points can also fit onto the node points of the geodesic grid, which will be placed at a distance of approximately 2 metres from the centre where the sound source is placed. This distance follows other similar measurements elsewhere[11]. The grid design incorporates thin aluminium structural elements, and microphone sensor points integrated into the node joining pieces.

A number of instruments are planned to be measured including some for which no current data exists[8]. The data can then be analysed using a spherical harmonic decomposition[12], which will allow the sound radiation pattern to be encoded and stored independently of the arbitrary sensor positions. Further measurements should also yield confirmation of existing data sets, with less high frequency interpolation data due to the distance between sensor points[9].

3. MEASUREMENT DATA

Fig.1, shown below, shows seven test sensor positions which were used in order to make some initial tests in the horizontal plane only, at a test radius of 1m. The test musical instrument used was a Lowden O-35 steel string guitar, playing a single 'A' note of fundamental frequency 100Hz.
The angular positions are given in this table:

Sensor position	**Angle**
Position 1	-90^o
Position 2	-60^o
Position 3	-30^o
Position 4	0^o
Position 5	$+30^o$
Position 6	$+60^o$
Position 7	$+90^o$

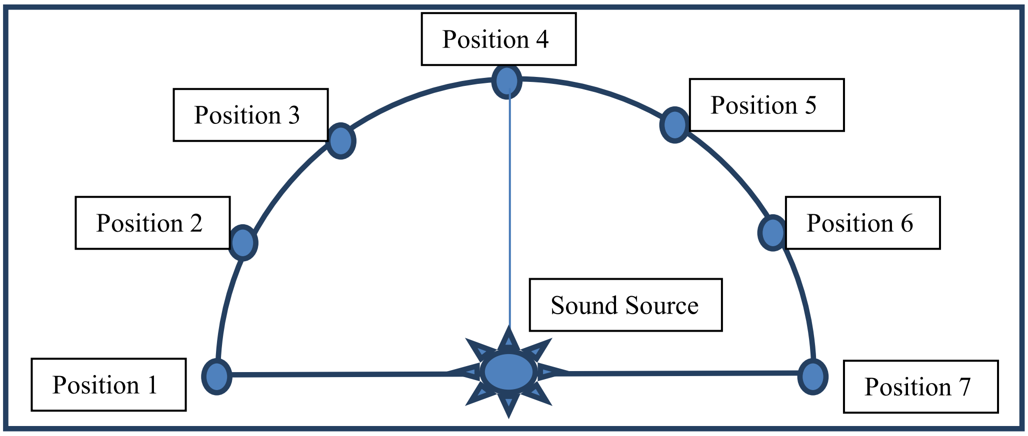

Fig. 1. Test Sensor Positions

The test recording was not made in an anechoic environment, as the emphasis was not on the integrity of the data, but to actually gather some test data to work with to progress the workflow and data processing elements of the project. The output of the microphone sensors was then compared and interpolated as shown in the following frequency-amplitude graphs, Fig.'s 2-10. These figures show amplitude in dB Full Scale on the vertical axis (relative to 0dB on the 24bit recording medium) and the horizontal axis shows frequency in Hz.

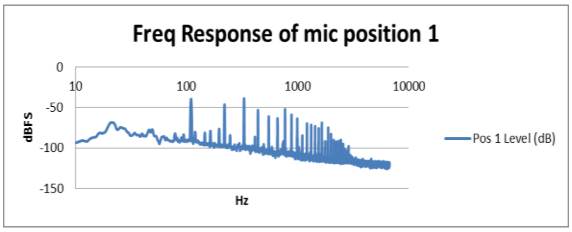

Fig. 2. Frequency Response of mic 1.

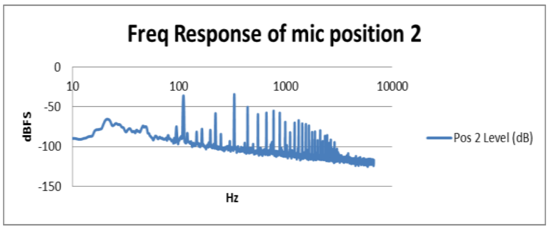

Fig. 3. Frequency Response of mic 2.

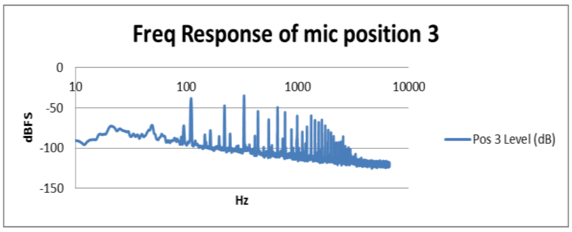

Fig. 4. Frequency Response of mic 3.

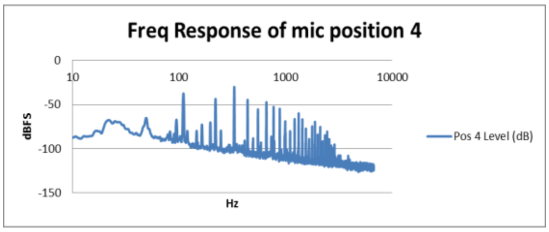

Fig. 5. Frequency Response of mic 4.

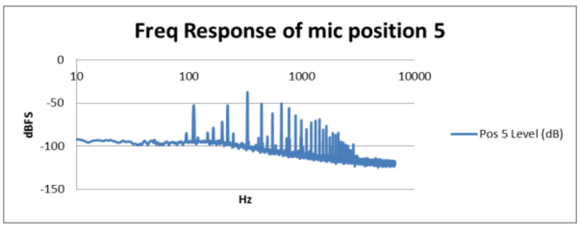

Fig. 6. Frequency Response of mic 5.

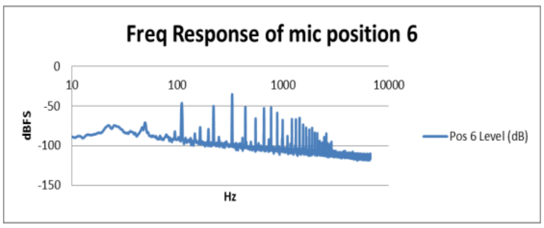

Fig. 7. Frequency Response of mic 6.

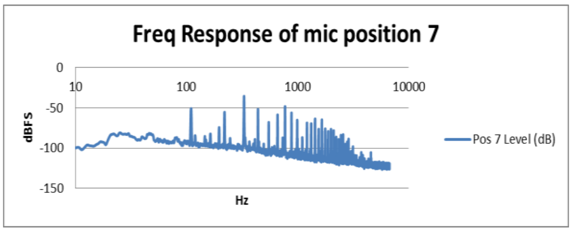

Fig. 8. Frequency Response of mic 7.

Comparing two of the data points from 0^{O} on axis (position 4) and 30^{O} to the right (position 5) we can see when the frequency plots are overlaid (in Fig. 9.) that there is a difference in the radiated energy in these two directions. As a proof of concept within the project, measurements from positions 4 and 5 were interpolated linearly between amplitude values at each frequency, as seen in Fig.10.

Fig. 7. Frequency Response of mic

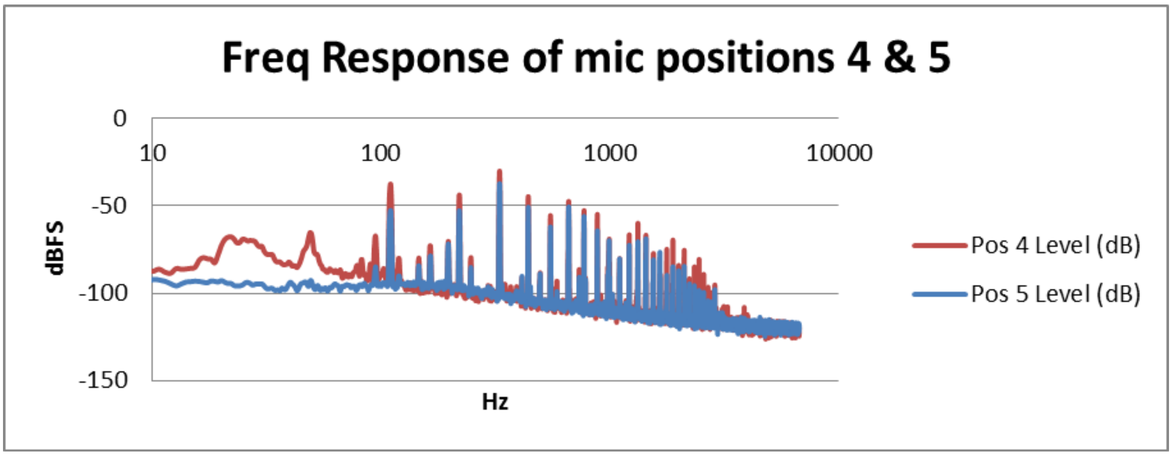

Fig. 9. Frequency Response of mics 4 and 5 shown

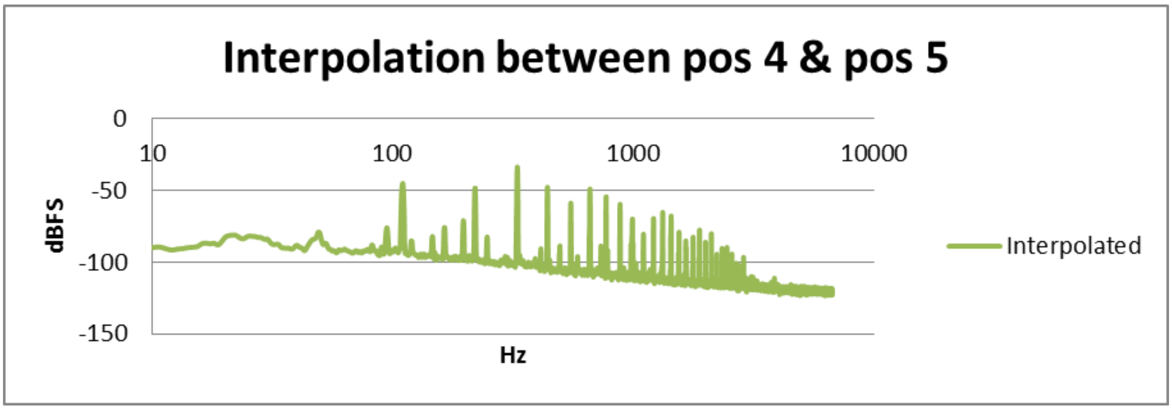

Fig. 10. Interpolated data between positions 4

The interpolation is valid up to approximately 650Hz, as the spacing between the sensors was set at approximately 0.52 metres. The interpolation halfway between sensor points 4 and 5 shown in Fig.10 can be taken as reasonable for the first five harmonic components (110-550 Hz). By varying the weight of contribution of each sensor's data in the interpolation, the response at any angle within the sensor array around the source could be predicted up to this limit.

4. RADIAL DATA DISPLAY

The issue of how to display the frequency-amplitude data for multiple radiated directions has been addressed in a number of ways. These include polar-response waterfall display as utilised by MLSSA software, shown in Fig11, taken from[13]:

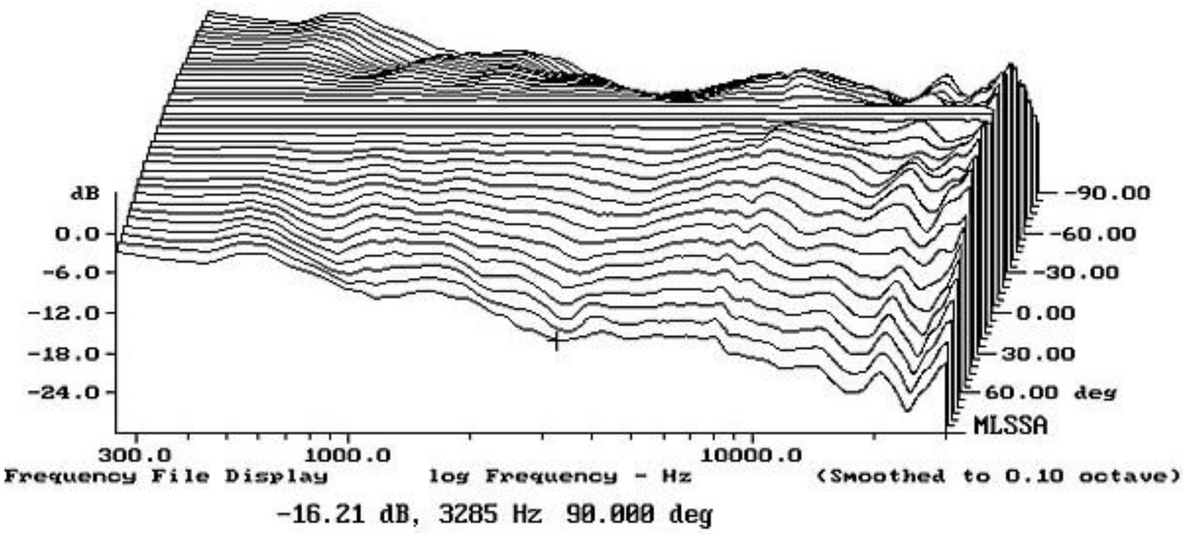

Fig.11. MLSSA polar-response waterfall plot[13].

Other common methods to display how the radiation of sound changes with angle and frequency introduces colours onto a straight line (although logarithmic scale) frequency plot, with radiated angle on a vertical scale and the amplitude shown as a colour contour. This is sometimes known as a 'Christmas Tree' plot as for many loudspeakers it looks like a fir tree on its side. An example is shown in Fig 12 from[14] :

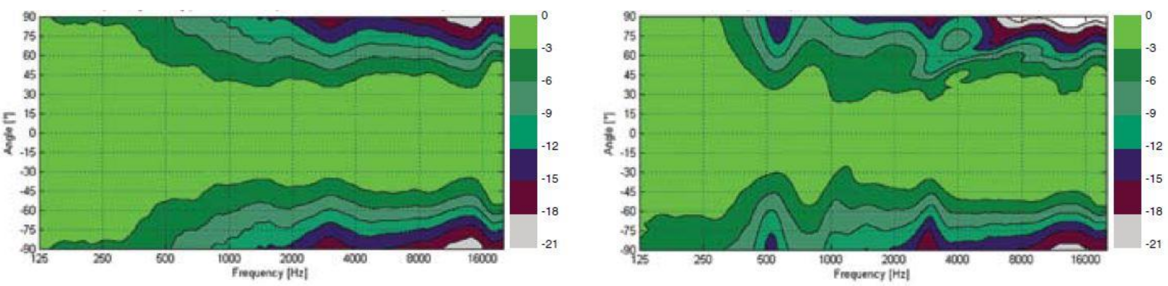

Fig.12. Horizontal (left) and Vertical (right) radiation of Genelec 8026a speaker[14].

The data for each radiation direction measured (in this test case we have data for 7 individual radial directions from the source) can be shown as individual frequency-amplitude plots (as in Fig.'s 2-8 above). This allows us to see the relative strengths of the harmonic components as they are radiated in different directions, but comparing them can be difficult unless two plots are overlaid, as in Fig. 9 above.

Another option is to use a colour representation of the amplitude data, as shown here in Fig. 13:

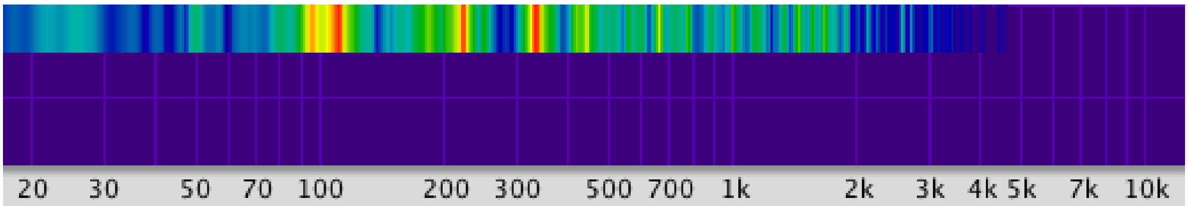

Fig.13. Colour Amplitude representation for mic position no.3.

In this representation, the higher amplitudes are shown as 'hotter' colours, i.e. red, with the lower amplitudes shown as blue. The variation from high to low amplitude follows the colour spectrum. Fig.13 shows clearly the red lines indicating harmonic components of the A 110Hz fundamental along with harmonics at 220Hz and 330 Hz, plus a lower level (shown in yellow) 440Hz harmonic. This can be seen to reflect the relative levels of these harmonics as shown in Fig.4, especially for example the higher amplitude 330Hz and the lower amplitude at 440Hz.

This representation allows us to see in a straight line the frequency-amplitude data for this sensor direction. So, we can combine a number of these straight line colour representations together with the direction of the straight line representing the direction of radiation from the sound source. If we do this using the 7 measurements shown above, we get the following radial plot (Fig.14.). This can be considered a 'frequency polar' plot.

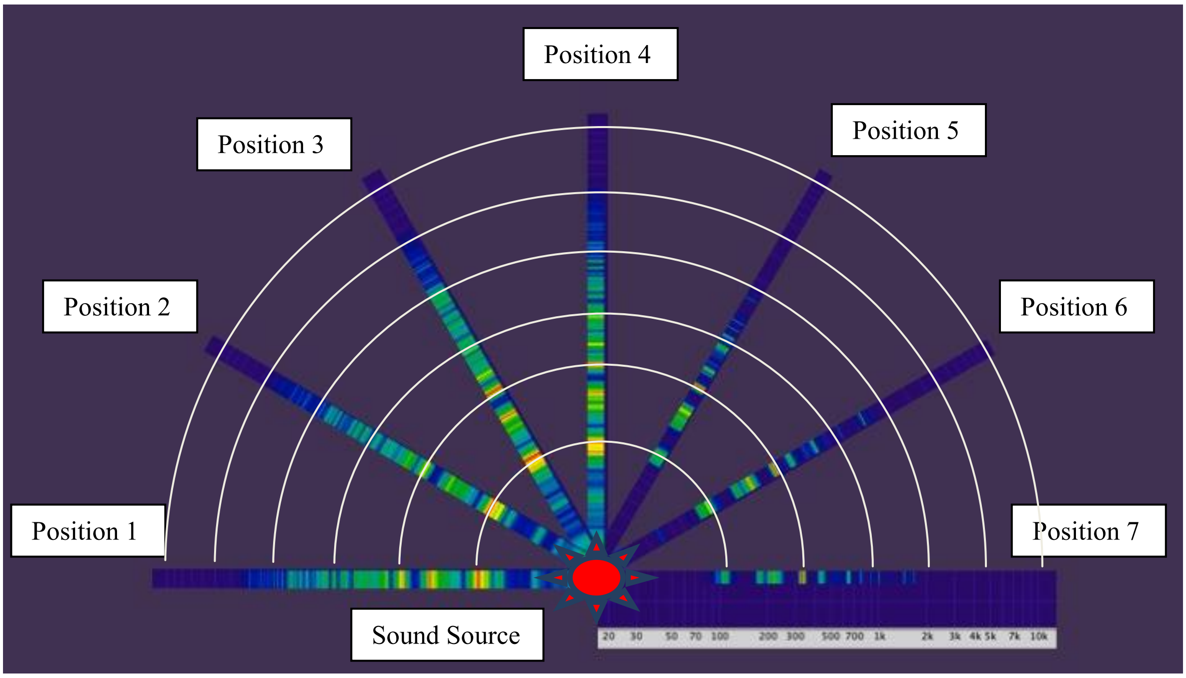

Fig.14. Colour Amplitude representation for all measured radiated directions.

From the measured data, we could then interpolate between the measured points and show it on the radial plot. This is illustrated in Fig 15 below (however, the data shown is not interpolated data, but rather the measured data spread out in order to illustrate the plotlines that the interpolated data would inhabit).

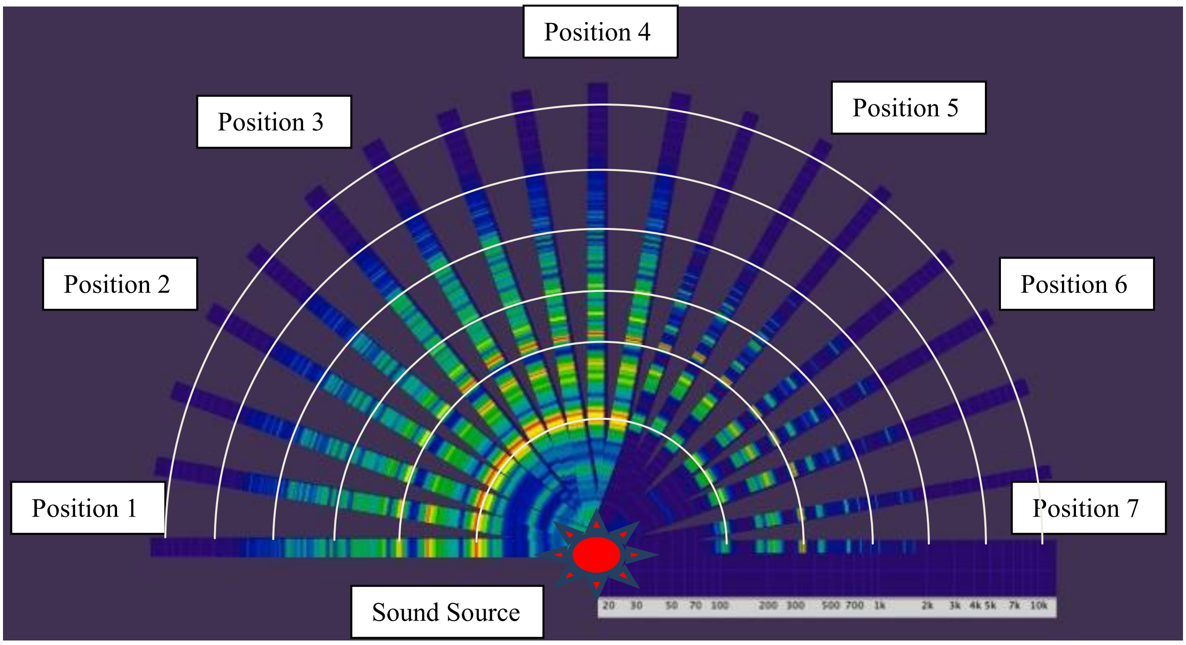

Fig.15. Radial Colour Amplitude representation of measured data with interpolated data positions illustrated by spreading out measured data.

5. FUTURE WORK

While there are already data sets for many musical instruments of varying resolutions, this project and the measurement system described can be used to verify this body of data, and will contribute data on instruments for which there is no current data set available[8,15].
As the number of sensors is almost twice that described in much of the previous literature, it could be used to improve the spatial resolution of many existing data sets[8,9,11,16]. It is also expected to verify that errors in high frequency interpolation are reduced when using higher spatial resolution data (as suggested by[9]). It is also possible to use the measurement system to examine the differences in instrument radiation characteristics between anechoic and reverberant environments, by making measurements of the same musical instrument in both environments.

6. CONCLUSION

Some basic results showing interpolation between a reduced set of data points have been presented. The measurement system utilising all planned data points will be able to gather a large body of acoustic radiation patterns of various musical instruments for which no information currently exists. The 3D data can also be used to build a model of a particular instrument or (by averaging a number of instruments of the same type) a model of that instrument type by using spherical harmonic component encoding.

The display of the relative frequency energy using a heat/colour graph in radial direction allows us to visualise directly how the acoustic energy radiates from the sound source. This is a more intuitive display than the more traditional frequency-waterfall or ‘Christmas Tree’ plot types. There is some similarity to directional wind-speed plots[17], but the next step is to extrapolate to 3D from the 2D frequency polar plot.

On a spherical/geodesic grid where the node points are mapped, the interpolation means that the radiated output from any direction could be found. This 3D data can then be used to build up a complete map of the output of the instrument, which could be coded as a set of spherical harmonic data, facilitating easy comparison of the energy content at different frequencies between any 2 directions of radiation described as points on the sphere.

7. REFERENCES

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