Comparison of spatial audio techniques for use in stage acoustic laboratory experiments

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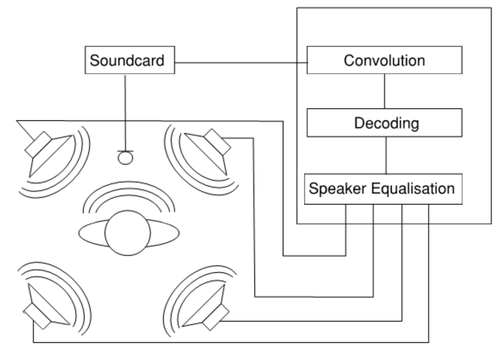
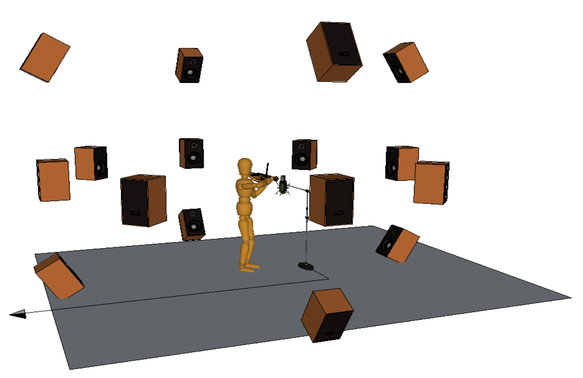
1. Stage acoustics laboratory tests

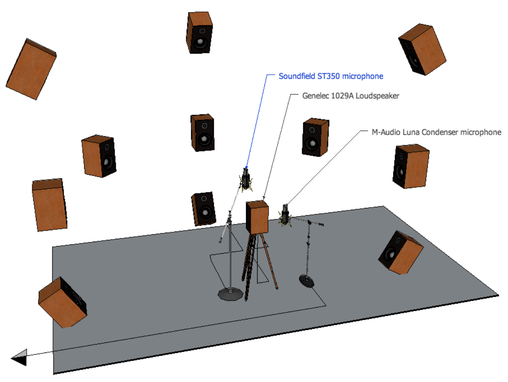
This project aims to study the effect of stage acoustic conditions on a performer by auralising the performance environment in response to the sound of their instrument in real-time. It is critical that early reflections are spatialised accurately to ensure the musician is experiencing the correct conditions. In particular, this work compares First Order Ambisonics (FOA) and Spatial Impulse Response Rendering (SIRR) when used to auralise a soundfield from the performer's perspective over a 16-channel loudspeaker array. An objective comparison of the techniques was conducted by analysing the rendered soundfields measured at the array sweetspot. Informal listening tests were also carried out based on a typical stage acoustic, performer-based, scenario.



System diagram of a typical loudspeaker based real-time auralisation system



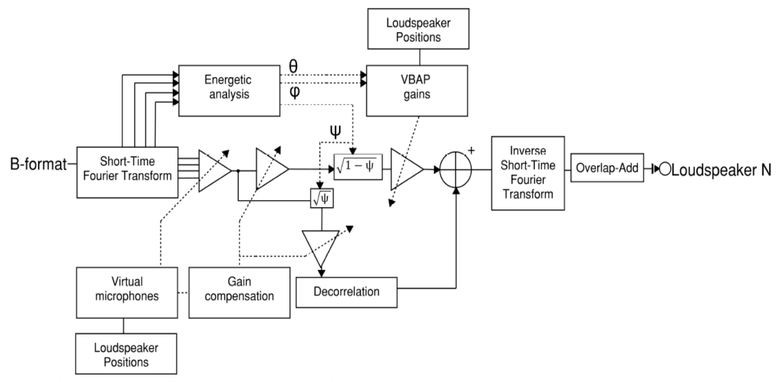
Model of musician playing in 16-channel real-time auralisation system



Model of experimental set up showing Soundfield microphone and loudspeaker used to measure auralised soundfield. (Array loudspeakers on one side have been omitted for clarity)

2. Spatial Impulse Response Rendering

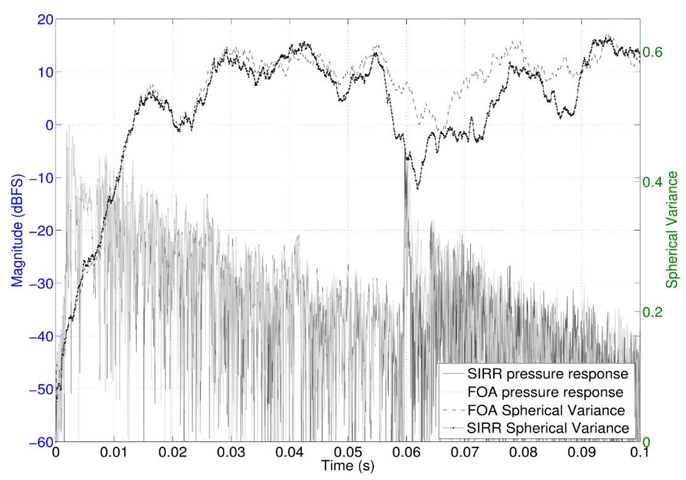
SIRR is a perceptually-motivated spatial audio technique which analyses a 3D soundfield for features which translate to auditory localisation cues. It estimates the angle of arrival and diffuseness of reflections in a 3D impulse response and re-synthesises these features for individual speaker feeds using Vector Based Amplitude Panning (VBAP) for directional components, and decorrelated audio distributed equally to the loudspeakers for the diffuse residual.



System diagram of analysis-synthesis technique shown for a single loudspeaker channel

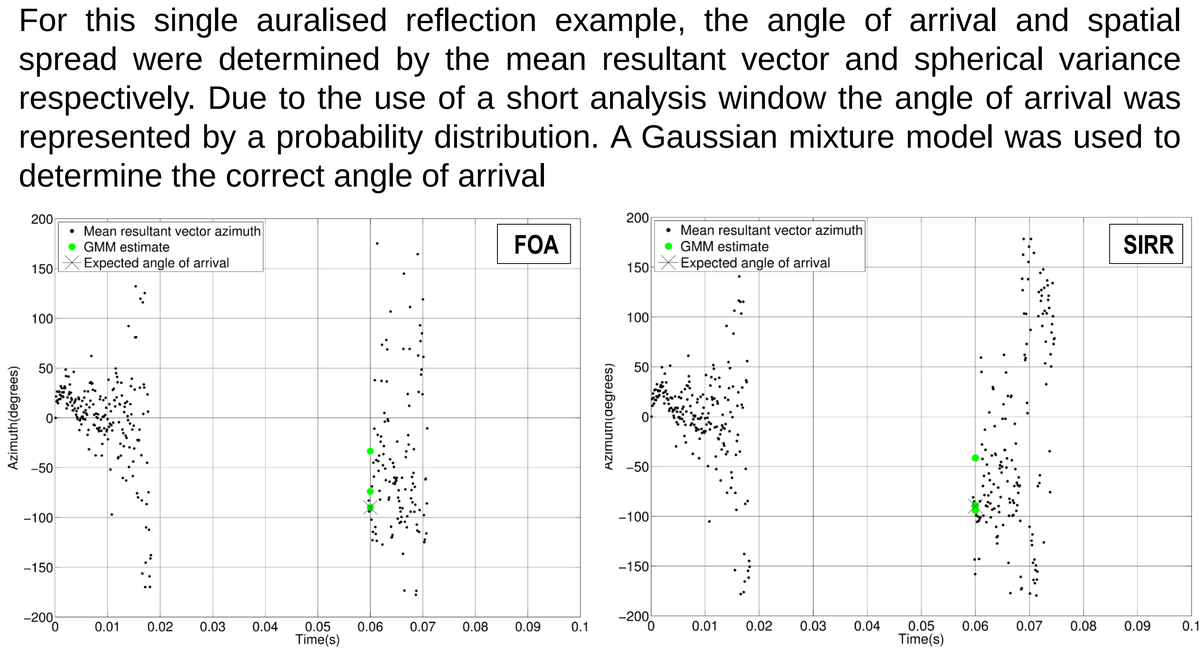
3. Objective tests

The spatialisation accuracy of FOA and SIRR rendered auralisations was tested by measuring impulse responses at the sweetspot of the loudspeaker array. A sine sweep was played through a loudspeaker (to emulate a musical instrument) and auralised in real-time based on a single, synthesized reflection. The result was then measured with a soundfield microphone.



Composite plot showing measured FOA and SIRR Sound Pressure Level envelopes (dBFS) and the associated spherical variance. This example shows the direct sound from the loudspeaker (that includes the early response of the SoundLab) and a single reflection occurring at t = 60ms.

An objective comparison of the spatialisation quality was achieved by intensity vector analysis of the rendered soundfields as measured at the array sweetspot. For this single auralised reflection example, the angle of arrival and spatial spread were determined by the mean resultant vector and spherical variance respectively. Due to the use of a short analysis window the angle of arrival was represented by a probability distribution. A Gaussian mixture model was used to determine the correct angle of arrival



Plots of the mean resultant vector for an impulse response consisting of a reflection at t = 60ms arriving at -90° azimuth. Results with diffuseness > 0:55 have been omitted for clarity. The cross represents the expected angle of arrival. The larger green dots (GMM component means) show the estimated angle of arrival.

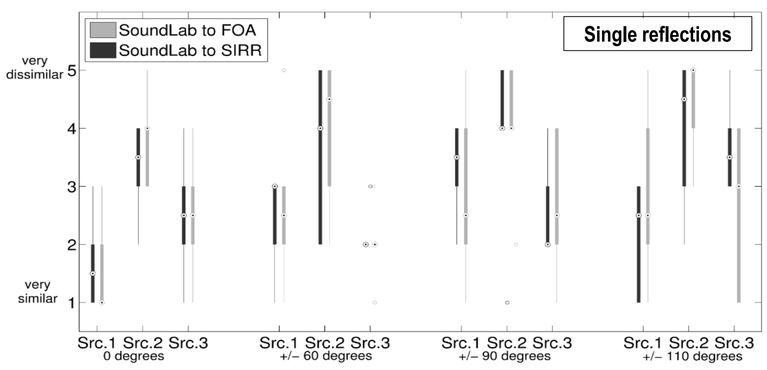
Results

Single reflections were spatialised equally well when rendered using FOA or SIRR. FOA demonstrates a slightly higher spherical variance, and so a reflection auralised with FOA is more spatially diffuse than an equivalent reflection auralised with SIRR. Both FOA and SIRR produced the correct angle of arrival.

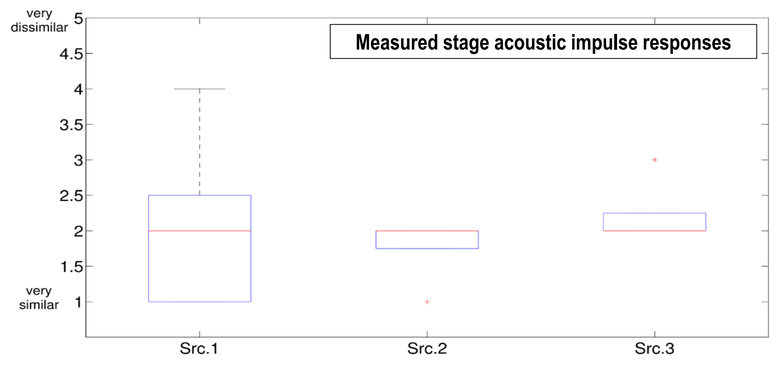
4. Subjective tests

Participants were played 47 pairs of musical samples through a forward facing loudspeaker emulating the direct sound of a musical instrument. In each pair the sound from the loudspeaker was auralised in real-time using either FOA, SIRR or direct sound only. Participants were asked to rate the similarity of each sample pair. Six untrained participants took part in the test.

The musical samples consisted of a legato cello (Source 1), a staccato clarinet (Source 2) or a sustained clarinet note (Source 3). The impulse responses used to auralise the samples were either single synthesised reflections arriving from set angles of arrival, or a measured stage acoustic impulse response.



Listening test results for sounds auralised with a single reflection rendered with FOA or SIRR compared to no reflection. Thick lines indicate 25 and 75 percentiles, thinner lines show the extremities of the data points, dots within boxes indicate the median while circles indicate outliers



Listening test results for sounds auralised with a measured impulse response rendered with FOA compared with SIRR. Central lines indicate the median response while box edges indicate 25th and 75th percentiles, outliers are indicated by crosses

Results

The majority of test subjects detected the single reflection example equally well when rendered with FOA or SIRR. Most test subjects detected the single reflection example more easily when the angle of arrival was displaced by a greater angle on the horizontal azimuth from the direct sound, or when the source contained dynamic phrasing (Source 2 - the staccato clarinet sample).

5. Conclusions and Future work

These tests indicate SIRR and FOA produce similar objective and subjective results when used in the context of stage acoustic laboratory experiments. SIRR is therefore viable for future use over existing FOA methods with the additional potential for parameterisation to simulate various stage acoustic conditions.

Future work will focus on:

- Further development of SIRR to investigate how changes in early reflection delivery are perceived by performers.
- Development of intensity vector analysis to enable detailed spatio-temporal analysis of early reflections on stage.
- Listening tests with performing musicians.