Charactersing radiation patterns of non-stationary sound sources with scanning techniques

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Abstract

Scanning techniques allow reducing significantly the number of sensors required to characterise a time-stationary sound field. Therefore, it is possible to produce sound maps by moving a transducer and tracking its position along the measurement. Conventionally, any change during the measurement would not be taken into account and non-stationary conditions are not suitable for measuring with scanning methods. However, this paper explores the advantages of using a static reference sensor close to the noise source in order to track any variations in the sound field during the measurement. The technique developed is based on taking transfer functions between the scanning transducer and the reference sensor. Then, the number of measured positions is limited for each frequency evaluating the dynamic range acquired. Some experimental results of mapping sound radiation patterns of a musical instrument are presented along with a discussion focused on the advantages and disadvantages of the method.

Introduction

Scanning methods are proven to minimize the measurement time and cost, but conventionally constrained to mapping stationary sound fields. In the literature of Near field Acoustic Holography (NAH), several signal processing techniques have been proposed to overcome some problems derived from the degree of time stationary of the source [1, 2]. However, these techniques require using multiple references along with scanning microphone arrays. In contrast, this paper is focused on presenting an efficient method for directly visualizing sound radiation patterns without back-propagating the sound field to the source and using only one fixed and one moving sensor.

A musical instrument is a classic example of non-stationary sound source. There are no standard regulations regarding the measurement procedure required for characterizing them due to practical difficulties. Therefore, finding a measurement technique which allows to assess the sound radiation of a non-stationary source in a fast and efficient way will be remarkably valuable. In this paper an adapted version of conventional Scan & Paint [4] is presented.

Theory

Radiation patterns of sound sources are useful to assess how much energy is emitted from different directions. Conventionally, the power distribution of a source can be estimated by calculating its power spectral density (PSD) at different spatial positions[3]. By definition the PSD of a non-stationary source will change along time. This fact implies that multiple channels would be required for tracking sound power changes across space and time. Hence, it is necessary to implement a different approach in order to measure sound radiation under non stationary conditions. In order to take into account time variations it is necessary to link the moving transducer with a fixed reference sensor in a relative sense. Tracking the position of the moving sensor across time makes possible to obtain transfer functions between both sensors across the space, which are directly related with the radiation patterns of a sound source. Several methods can be chosen depending on the signal which is likely to have undesired noise. In the case described above, the moving sensor is exposed to manipulation noise and the signal to noise ratio between direct and reverberant field will be smaller. Consequently, the estimator H_1 has been implemented because it is unbiased with respect to the presence of output noise. The transfer function estimator H_1 is defined as

$$H_1(f) = \frac{S_{p_s p_r}(f)}{S_{p_r p_r}(f)} \tag{1}$$

where the term $S_{p_s p_r}$ represents the cross power spectral density (CPSD) between two finite time signals p_s (scanning pressure) and p_r (reference pressure) of length T, i.e.

$$S_{p_s p_r} = \lim_{T\to\infty} \frac{E\left[P_s(f)P_r^*(f)\right]}{T} \tag{2}$$

where $P_r^*(f)$ is the complex conjugate Fourier transform of p_r and $P_s^(f)$ is the Fourier transform of p_s .

Instrumentation and experimental setup

Scan & Paint measurements were carried out using a Microflown PU probe which contains a pressure microphone along with a particle velocity sensor. The reference signals were measured using a GRAS pressure microphone and an accelerometer attached close to the bridge of the violin. In addition, a camera "Logitech Webcam Pro 9000" was required for recording a video of the sweeps. Measurements were performed in a small room with highly acoustic absorbent walls for minimising the influence of the reverberant field; thus, allowing to capture the direct sound radiated by the violin. Two sweeps of approximately one minute were undertaken over the top and bottom of the musical instrument.

Results: sound radiation measurements

This section present an example of how the measurement procedure presented can be used in challenging scenarios such as musical instrument measurements.

Figure 1 shows the front radiattion pattern of a violin playing only the highest string. The continuously changing sound field can be assessed as if it was stationary by calculating the transfer functions across the measurement plane. As a result, smooth radiation pattern can be visualized with a clear maximum over the area where the string was bowed.

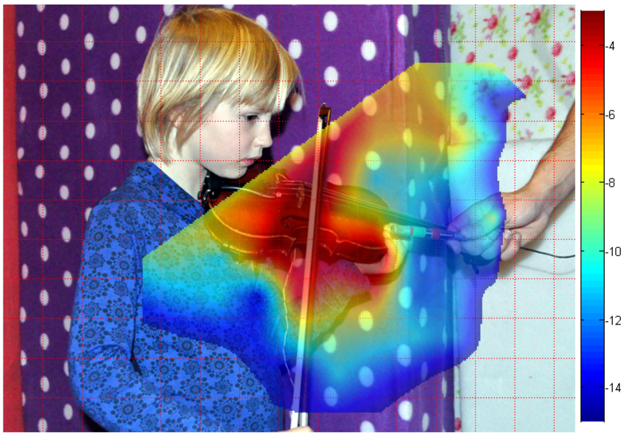

Figure 1: Radiation pattern of a violin calculated from pressure transfer functions at 1340 Hz (dBFS).

Furthermore, Figure 2 presents a particle velocity map of the bottom of the violin. As can be seen, taking the transfer function between fixed accelerometer and the moving Microflown sensor within a narrow frequency band lead to visualize the operational deflection shape of the violin body.

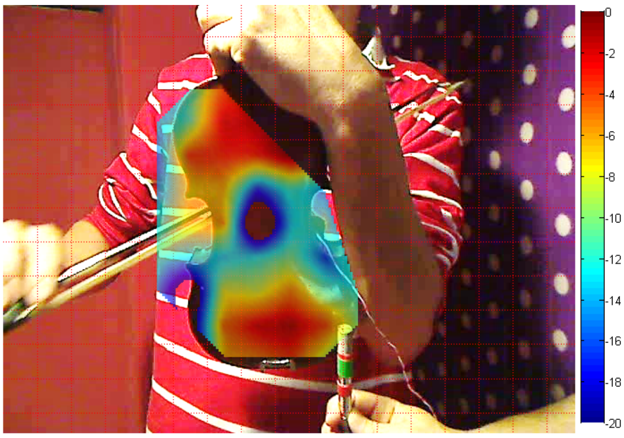

Figure 2: Operational deflection shape of the violin bottom calculated from particle velocity transfer functions at 1340 Hz (dBFS).

Advantages and disadvantages of the measurement method

Current methods for measuring non-time stationary sound field rely on using large sensor arrays. Alternatively, methods based on NAH can reconstruct the entire sound field by placing multiple reference transducers and then scanning an area with a large array. The novel technique proposed in this paper only requires two sensors: one static while the other is manually moved. Time, cost, simplicity and flexibility are the main issues evaluated in this section which determine the advantages and disadvantages of choosing a measurement technique.

Time required for setting up the instrumentation and performing the measurement is always a big issue. Manual sweeps of a single probe are a fast procedure for directly obtaining information about a sound field.

One of the main problems of most conventional array measurement systems is the cost of the equipment. Not only the number of transducer required for performing the measurements but also the multichannel acquisition system rise the price strongly. The proposed two-sensor solution has far less requirements than most of the current large multichannel applications.

The flexibility of the proposed method is one of its stronger advantages against array-based solutions. The novel technique allows to setup all instrumentation and resize the measurement plane just by moving the camera. Furthermore, the spatial resolution of the measurement is selected after performing the measurement allowing to assess several spatial distribution a posteriori.

Conclusions

A simple theoretical base for measuring time independent relative changes in a sound field has been given. The combination of the described principles with the scanning measurement technique Scan & Paint lead to a novel method for characterizing non-stationary sound fields using a scan based two-channel system. Results presented prove the successful implementation of the method. The proposed measurement technique achieves reductions on the number of transducers, time and cost required for performing non-stationary sound radiation measurements compared to conventional methods.

References

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