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SOUND POWER LEVEL ESTIMATION OF A MACHINE IN PRESENCE OF DISTURBING NOISE SOURCES

Gert De Sitter*, Patrick Guillaume and Abdoulahi Talal

Department of Mechanical Engineering, Vrije Universiteit Brussel
Pleinlaan 2, B-1050 Brussel, Belgium
gert.de.sitter@vub.ac.be (e-mail address of lead author)

Abstract

Nowadays a lot of industries try to lower the noise level at their plants and on their factory floors. In most cases the overall noise level is a result of the superposition of several noise sources. It is interesting to know the acoustic power of each of the individual sources. In other applications one is interested in the acoustic source power of a specific machine while it is impossible to stop the neighbouring machines in order to measure the source. In this contribution we discuss the theory and some experiments in which we try to estimate the acoustic source power in the presence of secondary noise sources.

INTRODUCTION

Nowadays a lot of techniques exist to identify noise sources. Most of these techniques serve a special purpose and have specific strengths and weaknesses. Some techniques concentrate on gathering high resolution data of a sound radiating machine while others try to reconstruct the radiated sound power of different distributed sources. A third category only wants to estimate the sound power level of a specific machine.

The first class of techniques focuses on noise source localisation and quantification. It comprises nearfield acoustic holography (NAH) [1, 2], beamforming (phased array techniques) and similar approaches. Typical applications are the acoustic analysis of engines and the visualisation of transmission loss defects [3]. The advantages of these techniques are that it is possible to locate accurately the sound sources and that they provide a full 3D description of the sound field. The disadvantages are that one needs microphone arrays (which are expensive) and that those techniques do not provide a power level estimation.

A second class of techniques also uses multiple microphones. But in this case these microphones don't have to be part of an array. The sources are estimated by inverting the a priori known transfer functions. Typical applications are the identification of multiple unknown distributed sources (e.g. in factories) [4]. The disadvantages are that one still needs a lot of microphones, one has to know the transfer functions in advance and that the problem can be ill-conditioned [5, 6]. An important advantage is that these techniques provide a lot of useful information.

A last class of techniques are those that are used to estimate the power level of a specific machine. Because of the fact that one isn't interested in the specific sound radiation field and the fact that there isn't an ill-conditioned inversion problem, it suffices to use a minimum of microphones. This certainly is a big advantage. These techniques are also standardised and are in conformity with some recent European Directives [7, 8]. This class can be divided into two subclasses: the simple sound pressure level measurements and the sound intensity techniques [9]. Both can be used to estimate the sound power level of stationary sources. The techniques that are based on the sound pressure level measurements are only useful in anechoic situations while the intensity techniques also can be used in normal rooms.

In this paper we will try to make the power level estimation techniques more robust so they can be used to estimate the sound power level in presence of disturbing noise sources. We will focus on the sound pressure level measurements although the theory also will be valid for the intensity measurements.

THEORY

Suppose we want to know the sound power level of a sound source Q which produces a random stationary sound. We will estimate this by using the sound pressure level measurements of N_m microphones. Because of the stochastic nature of the sources we will measure a number of N_b blocks. Suppose - for simplicity - that there is only one uncorrelated disturbing noise source E which also produces a random sound. So the sound pressure level spectrum of microphone i and block b can be symbolised by $P_{i,b}(\omega)$ with $i = 1 \ldots N_m$, $b = 1 \ldots N_b$ and ω the frequency. $P_{i,b}(\omega)$ can be modelled as:

$$P_{i,b}(\omega) = H_i^q(\omega) \cdot Q(\omega) + H_i^e(\omega) \cdot E_b(\omega) \tag{1a}$$

with

$H_i^q(\omega)$	the FRF between the sound source of interest and microphone i	(1b)
$H_i^e(\omega)$	the FRF between the disturbing noise source and microphone i	

If we place an additional reference microphone very near the sound source Q, we get the following measurement.

$$P_{q,b}(\omega) = H_q^q(\omega) \cdot Q(\omega) + H_q^e(\omega) \cdot E_b(\omega) \tag{2a}$$

with

$H_q^q(\omega)$	the FRF between the sound source and the reference microphone	
$H_q^e(\omega)$	the FRF between the disturbing noise source and the reference microphone	(2b)

Since the reference microphone is very close to the sound source of interest we can assume that equation (2a) can be simplified:

$$P_{q,b}(\omega) = H_q^q(\omega) \cdot Q(\omega) \tag{3}$$

Combining (1a) and (3) results in:

$$P_{i,b}(\omega) = \frac{H_i^q(\omega)}{H_q^q(\omega)} \cdot P_{q,b}(\omega) + H_i^e(\omega) \cdot E_b(\omega) \tag{4}$$

Sound Power levels when no disturbing sound sources are active

Now let us calculate the sound power level of microphone i when no disturbing sound sources are present. We use for this situation a superscript 0. In this situation equation (4) can be simplified:

$$P_{i,b}^0(\omega) = \frac{H_i^q(\omega)}{H_q^q(\omega)} \cdot P_{q,b}(\omega) \tag{5}$$

To estimate the sound power level we calculate the autopower spectrum of microphone i:

$$G_{i,i}^0(\omega) = \sum_{b=1}^{Nb} \left(\frac{H_i^q(\omega)}{H_q^q(\omega)} \cdot P_{q,b}(\omega) \right) \cdot \left(\frac{H_i^q(\omega)}{H_q^q(\omega)} \cdot P_{q,b}(\omega) \right)^* \tag{6}$$

$$= \left| \frac{H_i^q(\omega)}{H_q^q(\omega)} \right|^2 \cdot \sum_{b=1}^{Nb} \left(P_{q,b}(\omega) \cdot P_{q,b}^*(\omega) \right) \tag{7}$$

$$= \left| \frac{H_i^q(\omega)}{H_q^q(\omega)} \right|^2 \cdot G_{q,q}(\omega) \tag{8}$$

In equation (8) $G_{q,q}(\omega)$ stands for the autopower spectrum of the reference microphone.

Sound Power levels with disturbing sound sources

In this case we calculate the autopower spectrum of microphone i but now we use equation (4) in stead of equation (5).

$$\begin{aligned} G_{i,i}(\omega) = \sum_{b=1}^{Nb} & \left(\frac{H_i^q(\omega)}{H_q^q(\omega)} \cdot P_{q,b}(\omega) + H_i^e(\omega) \cdot E_b(\omega) \right) \\ & \cdot \left(\frac{H_i^q(\omega)}{H_q^q(\omega)} \cdot P_{q,b}(\omega) + H_i^e(\omega) \cdot E_b(\omega) \right)^* \end{aligned} \tag{9}$$

Knowing that the sound source and the disturbing sound source are uncorrelated and symbolising the autopower spectrum of the disturbing sound sources by $G_{e,e}(\omega)$ equation (9) can be simplified:

$$G_{i,i}(\omega) = \left|\frac{H_i^q(\omega)}{H_q^q(\omega)}\right|^2 \cdot G_{q,q}(\omega) + |H_i^e(\omega)|^2 \cdot G_{e,e}(\omega) \tag{10}$$

Combining (8) and (10) results in:

$$G_{i,i}(\omega) = G_{i,i}^0(\omega) + |H_i^e(\omega)|^2 \cdot G_{e,e}(\omega) \tag{11}$$

Equation (11) shows that the autopower spectrum that we calculate from the sound pressure level measurements in the situation of active disturbing sound sources $(G_{i,i}(\omega))$ is the sum of the autopower spectrum that we calculate from the sound pressure level measurements in the situation when no disturbing sound sources are active $(G_{i,i}^0(\omega))$ and a term that is dependant of the auto power spectrum of the disturbing sound sources.

Solving the problem

The problem one faces is to estimate the auto power spectrum of microphone i in a way that the influence of the disturbing sound sources is eliminated, i.e. to calculate $G_{i,i}^0(\omega)$. From equation (8) one can conclude that $\left|\frac{H_i^q(\omega)}{H_q^q(\omega)}\right|^2$ is unknown.

This problem can be solved using the crosspower spectrum of the sound pressure of microphone i and the sound pressure of the reference microphone. The notation we will use is $G_{i,q}(\omega)$. Also one has to assume that the sound pressure measurement of the reference microphone and the disturbing noise sources are uncorrelated.

$$\begin{aligned} G_{i,q}(\omega) &= \sum_{b=1}^{Nb} \left(P_{i,b}(\omega) \cdot P_{q,b}^*(\omega)\right) && (12) \\ &= \sum_{b=1}^{Nb} \left(\frac{H_i^q(\omega)}{H_q^q(\omega)} \cdot P_{q,b}(\omega) + H_i^e(\omega) \cdot E_b(\omega)\right) \cdot P_{q,b}^*(\omega) && (13) \\ &= \frac{H_i^q(\omega)}{H_q^q(\omega)} \cdot G_{q,q}(\omega) && (14) \end{aligned}$$

From equation (14) it follows that:

$$\left|\frac{H_i^q(\omega)}{H_q^q(\omega)}\right|^2 = \left|\frac{G_{i,q}(\omega)}{G_{q,q}(\omega)}\right|^2 \tag{15}$$

So equation (8) can be solved:

$$G_{i,i}^0(\omega) = \left|\frac{G_{i,q}(\omega)}{G_{q,q}(\omega)}\right|^2 \cdot G_{q,q}(\omega) \tag{16}$$

EXPERIMENTS

The experiment setup consisted of two loudspeakers that were placed in an anechoic chamber. One loudspeaker served as the source which had to be identified, the second one served as a disturbing noise source. Two different white noise generators were used as input so the sound sources were uncorrelated. Two microphones were used: the measuring microphone was placed between the 2 loudspeakers; the reference microphone was placed 10 cm from the loudspeaker which served as the source. The signals were sampled at 8192 Hz.

In a first experiment most of the measured sound was due to the sound source. Only in the frequency band from 2300 Hz till 3000 Hz the disturbing noise was dominating in the measured sound pressure of the measuring microphone (see Figure 1). Figure 2 shows that the estimate is of good quality.

In a second experiment the disturbing noise source was dominating (see Figure 3). Averaging over 180 blocks of data still resulted in excellent estimates (see Figure 3). Figure 3(c) shows the octave data of the estimates.

CONCLUSIONS

In this paper, a machine sound power level estimation technique has been proposed which is able to eliminate the influence of disturbing sound sources. The technique works as long as the machine which has to be identified is a stationary random sound source and the disturbing sound sources also are random sources. An additional condition is that the source and the disturbing sources have to be uncorrelated. The estimate of the sound power level of a pneumatic machines with other non-periodic disturbing sources is an example where the proposed technique can be applied.

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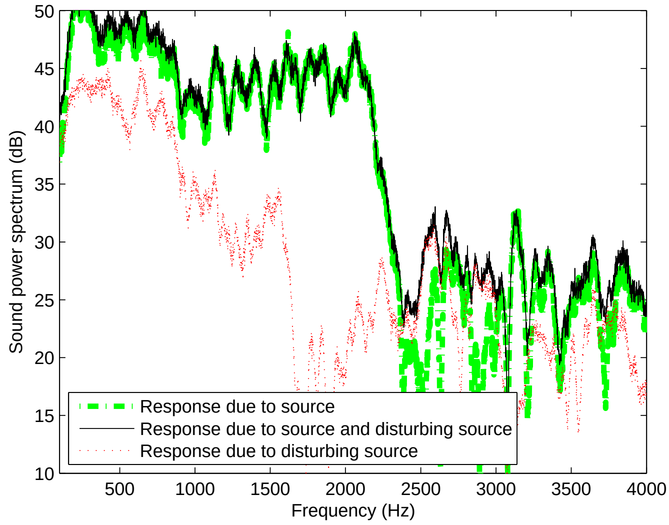
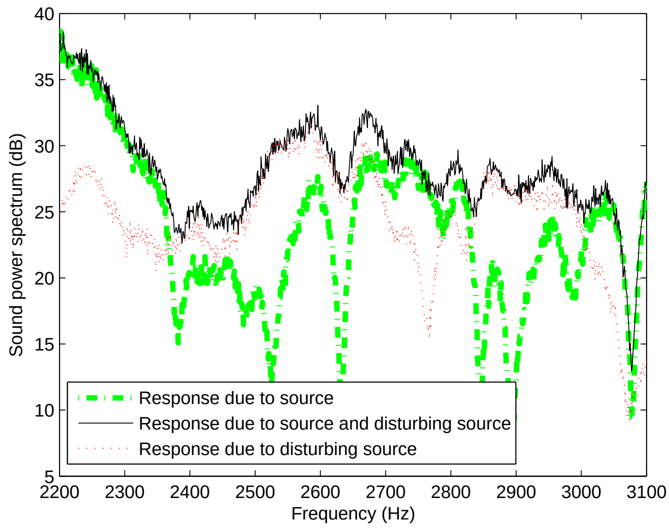


(a) Responses



(b) Responses (detail)

Figure 1: Microphone measurements of the first experiment

[2] W. Veronesi, J. Maynard, *Digital holographic reconstruction of sources with arbitrarily shaped surfaces*, Journal of the Acoustical Society of America, 85(2), (1989), 588–598.

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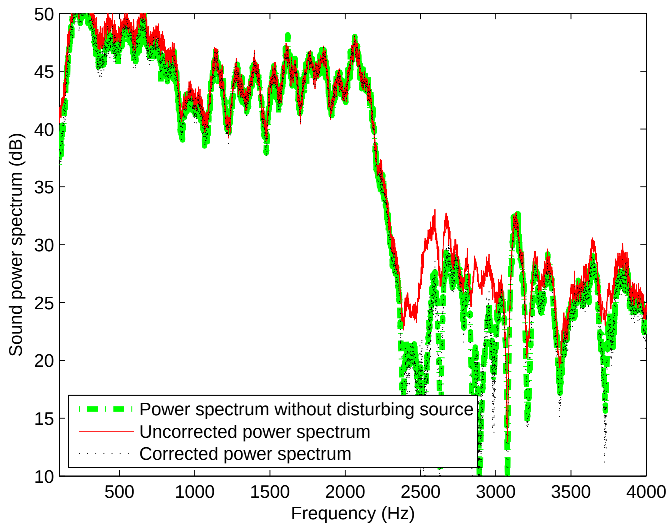

Figure 2: Estimation of the autopower spectrum of the sound source

401–417.

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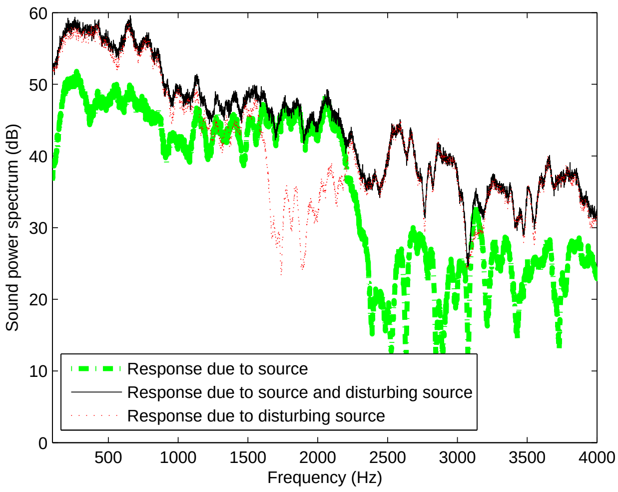
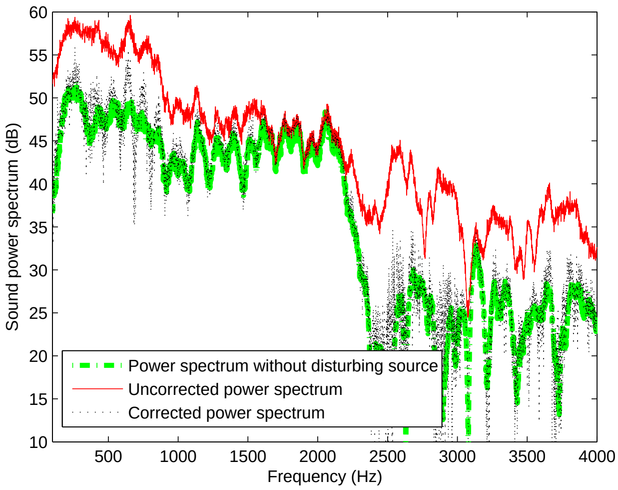
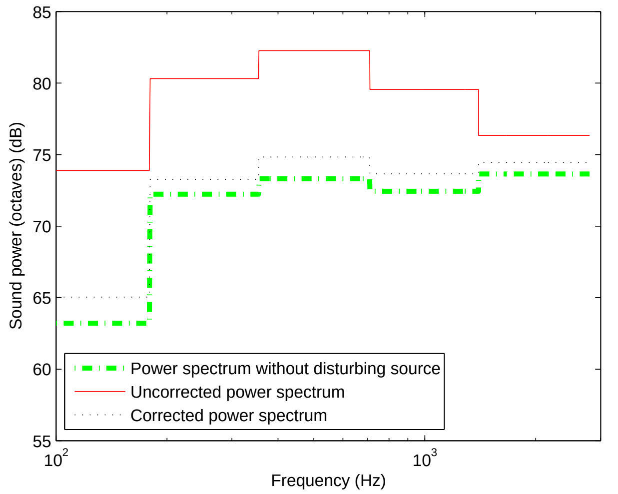


(a) Microphone measurements of the second experiment



(b) Estimation of the autopower spectrum of the sound source



(c) Estimation of the autopower spectrum of the sound source (octaves)

Figure 3: The second experiment