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QUALITY CONTROLLED SEPARATION OF OUTDOOR NOISE COMPONENT(S) CONTRIBUTED BY CONTINUOUSLY WORKING PLANTS APPLYING ONLINE MEASURED L_X-CONFIDENCE LIMITS

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ABSTRACT

In case of necessary assessment of already existing noise sources like industrial plants, the separation of the interesting sound component from the residual environmental noise is a well known common task. A method is presented which uses an appropriate noise evaluation index L_X (percentile) for this purpose, for instance L_{50}. As L_x index values from measurement, like those of any other kind of evaluation index, have limited accuracy due to the ubiquitous stochastic level fluctuations, this uncertainty should be explicitely taken into account within the assessment procedure. For this reason a software suitable for laptop PC has been developed for real time measurement of the L_X confidence limits. By these datas, transferred into a further appropriate processing software, it is possible to present the final results of the sound separation, their related confidence limits and the resolution limit of the separation method.
This new technique of quality control is demonstrated in the version for application to the noise assessment of continuously working plants like power stations etc., a some more sophisticated type of case than that of merely switching on or off the interesting single sound source. An example of a field measurement and its result is presented.

1. INTRODUCTION

At the immission sites of already existing and working stationary noise sources as factories, power stations etc. often relatively high residual sound pressure levels caused by traffic simultaneously are present, which are to be separated within the assessment process. This is a common necessity to meet legislation and regulations in favor of environmental protection, primarily based on the polluter pays principle. Since this problem is not new, there exist already numerous relating procedures as in measurement [1] as in prediction [2], also principally to be controlled by measurements. But there is no *additional* quality control performed to cover the advantageous high resolution, which in fact is achievable. Controlled precision is important for

the date base on which decicions are founded. On the other hand, as is well known, there exist measurement incertainties due to stochastical fluctuations that occur in the noise level on site. For this reason the technique described here was developed to separate the different noise sources. This is primarily in view to environmental protection, where usually the whole frequency rated sound pressure level is of interest.
The sound index L_x implies the freedom of an adequate choice of the partition parameter q in favor of significantly more sophisticated approach to noise component separation than by the L_{eq} index can be done. But this approach was only possible due to the evolution of computer based measurement systems within the last ten years [3]. By this development have opened up new possibilities to carry out extensive evaluation procedures more quickly, i. e. online, by aid of (personal) computer and appropriate software as generally reported about in [4].

2. BASIC FEATURES OF THE L_X-CONFIDENCE INTERVAL TO BE USED FOR NOISE COMPONENT SEPARATION

2.1 Confidence Interval

The accuracy of noise level indices conveniently can be quantified by a bracket confidence interval [5][6]. The half confidence interval , i. e. the level distance V_L of the upper and of the lower confidence limit $L_{u,x}$ and $L_{l,x}$ from the measured L_x value itself, resp. the positions of $L_{u,x}$ and $L_{l,x}$ themselves, can be evaluated in measurement practice by

$$V_L := L_{u,x} - L_x = L_x - L_{l,x} = t_{n-1;1-\alpha/2} \left|\frac{dL}{dq}\right| \sqrt{\frac{\hat{\nu}}{T}\left(q_u^2 s_w^2 + q_w^2 s_u^2\right)} \quad \text{dB} \qquad (1)$$

[6][7]. In eq. (1) denote (see also [7]): q: Partition parameter; u and w: Symbols for crossing down/up; $\hat{\nu}$: Observed mean of the crossing up/down frequency ($\hat{\nu} \cdot T \geq 5$); $q_u + q_w \equiv 1$.
The procedure denoted by formula (1) exploits the microstructure present in any stochastically varying signal with the benefit to describe the accuracy of L_x only by a short measurement. Some more detailed presentations are given already in [6][8] and in these proceedings [9].

For signal processing and representation of the L_x-accuracy given by eq. (1) by an online performance the neccessary software had been designed. For ten kinds of L_x (L_1, L_5, L_{10}, L_{30}, L_{40}, L_{50}, L_{70}, L_{90}, L_{95}, L_{99}), the confidence limits are calculated online at the confidence level 0,8 [10] and given onto screen and printer.

The reliability of this measurement technique was examined and confirmed by comparison of the results from eq. (1) with the direct but much more time expensive measurement of L_x-distributions from environmental (traffic) noise themselves. It turned out that the crossing up and down intervals are mutually independent again not until about 2,5 further crossings in the mean [10]. By this the confidence interval is spread by the "correlation factor" b = 1,6 (see also below, eq. (12) ff).

2.2 Relations to be used in the separation procedure

2.2.1 L_x level subtraction in the sound intensity space

The noise impact caused by two different sources mostly occurs independent of each other. Then, as is well known, they combine to the cumulative sound intensity distibution function (c.d.f.) of the superimposed sounds (index G in eq. (2)) by convolution. It can easily be shown [7] that, if the c.d.f. of the residual noise is locally linearized around its point of inflection and the partition q is chosen accordingly, the L_{eq} of the source to be assessed, denoted by Q, is

$$L_{eqQ} = 10\log\left[10^{0,1L_{qG}} - 10^{0,1L_{qR}}\right]. \qquad (2)$$

For environmental noise the optimal working range for eq. (2) is usually located around the L_{70} to L_{50} levels. To examine the bias which can occur in consequence of the local linearisation, model distibutions of plant and traffic noise, closely matched to the measured distributions, have been convoluted by computer. Besides this also everyday-like real time field measurements were carried out using a sound source to be assessed with a known immission value measured separately under very low residual level conditions. The mean bias of the final result L_{eqQ} showed to be typically about 0,3 dB [7].

2.2.2 Variance of the intensity difference

By application of the variance definition (see [5], ch. 1.4 and 5.1) on case of two measured levels $L^{(1)}$ und $L^{(2)}$ usually to be performed in intensity space having the half confidence interval (h.c.i.) measures $V_{L,1}$ and $V_{L,2}$ (in dB), the resulting half confidence interval of the sum or the difference is determined, in intensity terms, by

$$V_{I\,res}^2 = (0{,}23)^2 \cdot \left[10^{0,2L^{(1)}} \cdot V_{L,1}^2 + 10^{0,2L^{(2)}} \cdot V_{L,2}^2\right]. \qquad (3)$$

In field measurements the student factor t stabilizes soon, i. e. typically after 5 min for traffic noise and 3 min for continuously working plants ($>\cong$ 30 crossings). Then for the width of the h. c. i. measured by V_L the same addition rule eq. (3) is valid than for the variance itself.

2.2.3 Level of resolution limit

By use eq. (3) the resolution limit for extracting the L_{eq} of a sound source, which produces a only low level in comparison with the total level, easily can be derived. If the h. c. i. of the residual noise level is denoted by V_R and setting $b = 1{,}6$ this limit is

$$L_{rlQ} = L_R + 10\log(0{,}23\sqrt{2}\,b\,V_R) = L_R + 10\log V_R - 2{,}8 \quad \text{dB}. \qquad (4)$$

It is defined as the level whose lower confidence limit in intensity space equals zero.
Eq. (4) is the basis of the discriminatory power of the method described here.

2.2.4 Superposition theorems for two combined measurement time intervals

For a time symmetric measuring sequence to minimize bias caused by a level drift in time addition theorems for level and variance have been presented in [7]. They are applied below.

3. NOISE COMPONENT LEVEL SEPARATION

3.1 General conditions

There are to be determined parameter values for two system components i. e. the sound source to be assessed and the sum of all other, the residual (background) noise sources. For this reason it is to be measured at two different and independent conditions. One variant is merely switching the interesting single sound source on and out [10]. An other way described below is, to take **two** approriate measuring sites.

The model and procedure presented here requires the following conditions to be met:

a) The source to be assessed acts as a point source. This is the case within $\leq 0{,}1$ dB if the radiating structure extends not more than half of the distance to the nearer immission site.

b) The source related sound attenuation, additional to the 1/r^2-decrease, between the two chosen immission sites is known. It can be calculated by available standards [2].

c) The difference of the residual level between the measuring sites is known by an additional acoustical information or by a separate measurement, possibly also using the technique reported here. This condition is the crucial one and is to be checked carefully.

3.2 The immision model

The the separation of two sound level components of environmental noise, using the L_x sound index, is based on the following immission model, demonstrated in Fig. 1. There the basic parameters are definded as follows:

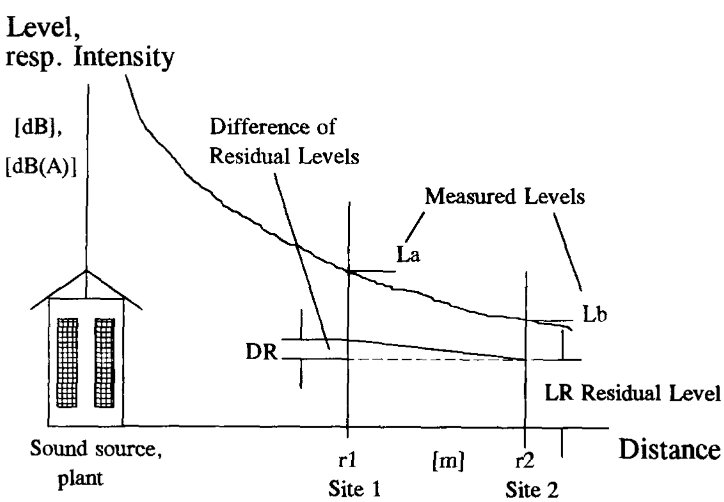

Figure 1: Immission model and parameters which enter the procedure of sound component level separation (schematically).

D_{12}: Source related sound attenuation between site 1 and site 2, additional to the corresponding 1/r^2-decrease;

L_{Qa}: Sound pressure level at site 1 produced by the source to be assessed (factory, ind. plant).

L_{Qb}: Sound pressure level at site 2 by the source.

γ: Ratio of the sound intensities from the source, arriving at site 1 and site 2.

At the present state of the art the L_{50} percentile levels are taken as the measured levels denoted by L_a and L_b.

At this point it is to be stated that this model looks quite conventional. But it is to be emphasized that the main, the additional feature is that now the accuracy of the primary level measurement is provided instantly and so available for further signal processing in favor of quality control.

Starting from the definitions given above the noise level component separation can be performed by the following set of equations:

$$10^{0,1L_a} = 10^{0,1L_{Qa}} + 10^{0,1(L_R + D_R)}, \quad (5) \qquad 10^{0,1L_b} = 10^{0,1L_{Qb}} + 10^{0,1L_R} \quad (6)$$

and

$$\gamma = (r_2 / r_1)^2 \cdot 10^{0,1D_{12}}. \quad (7)$$

3.3 Level, confidence limits and resolution limit of the source

3.3.1 Measurement begins at the site in *smaller* distance

Let be t_{11} the first measurement interval at site 1, t_2 the measurement interval at site 2 and t_{12} the second measurement interval at site 1, performed in this sequence. The corresponding measured levels (here L_{50}) be L_{a1}, L_b and L_{a2} and the corresponding observed h. c. i. values V_L be V_{11}, V_2 and V_{12} in dB. The 'correlation factor' is to be taken $b = 1,6$.

The representative level for the combined partial intervals t_{11} and t_{12} calculates by

$$10^{0,1L_a} = \frac{10^{0,1L_{a1}} \cdot t_{11} + t10^{0,1L_{a2}} \cdot t_{12}}{t_{11} + t_{12}} \quad (8)$$

(see [7]). From this we get the L_{eq} of the sound source, the industrial plant, at the two measurement sites by

$$L_{Qa} = 10\log\left[(10^{0,1L_a} - 10^{0,1(L_b+D_R)})/(1-10^{0,1D_R}/\gamma)\right] \quad (9)$$

and

$$L_{Qb} = 10\log\left[(10^{0,1L_a} - 10^{0,1(L_b+D_R)})/(\gamma-10^{0,1D_R})\right]. \quad (10)$$

The upper and lower confidence limits are determined for **site 1** by

$$L_{uQa} = 10\log\left[(10^{0,1L_a} - 10^{0,1(L_b+D_R)} + A_r)/(1-10^{0,1D_R}/\gamma)\right] \quad (11a)$$

and

$$L_{lQa} = 10\log\left[(10^{0,1L_a} - 10^{0,1(L_b+D_R)} - A_r)/(1-10^{0,1D_R}/\gamma)\right], \quad (11b)$$

where the additional quantities accounting for the spread of the source level are

$$A_1 = 0,23\,b\sqrt{(10^{0,2L_{a1}} \cdot V_{11}^2 \cdot t_{11} + 10^{0,2L_{a2}} \cdot V_{12}^2 \cdot t_{12})/(t_{11}+t_{12})}, \quad (12)$$

$$A_2 = 0,23\ b\ V_2\, 10^{0,1(L_b+D_R)}. \quad (13)$$

and the resulting overall spread

$$A_r = \sqrt{A_1^2 + A_2^2} \quad (14)$$

[7]. The resolution limit for the determination of the source level at **site 1** is at the level position

$$L_{lrQa} = 10\log\left[A_r/(1-10^{0,1D_R}/\gamma)\right]. \quad (15)$$

The upper and lower confidence limits are determined for **site 2** by

$$L_{uQb} = 10\log\left[(10^{0,1L_a} - 10^{0,1(L_b+D_R)} + A_r)/(\gamma-10^{0,1D_R})\right] \quad (16a)$$

and

$$L_{lQb} = 10\log\left[(10^{0,1L_a} - 10^{0,1(L_b+D_R)} - A_r)/(\gamma-10^{0,1D_R})\right]. \quad (16b)$$

The resolution limit for the determination of the source level at **site 2** is at the position

$$L_{rlQb} = 10\log\left[A_r/(\gamma-10^{0,1D_R})\right]. \quad (17)$$

3.3.2 Measurement beginns at the site in the *greater* distance

Analogous to the case, that the measurement begins at the site in the *smaller* distance it is now denoted as follows: t_{21} first measurement interval at site 2, t_1 measurement interval at site 1 and t_{22} second measurement interval at site 2, performed in this sequence. The corresponding measured levels (here L_{50}) are L_{b1}, L_a and L_{b2} and the corresponding observed half width of confidence level intervals are denoted by V_{21}, V_1 and V_{22} in dB. Again is $b = 1,6$.

The level representative for the combined partial intervals t_{21} and t_{22} calculates by

$$10^{0,1L_b} = \frac{10^{0,1L_{b1}} \cdot t_{21} + 10^{0,1L_{b2}} \cdot t_{22}}{t_{21} + t_{22}}, \quad (18)$$

analogous to eq. (8) to be inserted in eqs. (9) and (10).

For the calculation of the confidence and resolution limits by use of eqs. 11(a,b) and 16(a,b) respectively, the quantities, analogous to the case of beginning at site 1, are:

$$A_1 \;=\; 0{,}23\; b\; V_1\, 10^{0{,}1L_a}, \tag{19}$$

$$A_2 = 0{,}23\, b \sqrt{(10^{0{,}2(L_{b1}+D_R)} \cdot V_{21}^2 \cdot t_{21} \;+\; 10^{0{,}2(L_{b1}+D_R)} \cdot V_{22}^2 \cdot t_{22}) \,/\, (t_{21}+t_{22})} \tag{20}$$

and

$$A_r \;=\; \sqrt{A_1^2 + A_2^2}\,. \tag{21}$$

Using the eqs. (19) - (21) the resolution limits for the determination of the source levels at site 1 and 2 can be determined by the already given eqs. (15) and (16).

3.4 Level, confidence limits and resolution limit of the residual noise

The residual level at site 1 calculates as

$$L_{Ra} \;=\; 10\log\left[(\gamma \cdot 10^{0{,}1L_b} \;-\; 10^{0{,}1L_a}) \,/\, (\gamma - 10^{0{,}1D_R})\right] + D_R \tag{22}$$

and at site 2 as

$$L_{Rb} \;=\; 10\log\left[(\gamma \cdot 10^{0{,}1L_b} \;-\; 10^{0{,}1L_a}) \,/\, (\gamma - 10^{0{,}1D_R})\right]. \tag{23}$$

The upper and lower confidence limits of the residual level are determined for **site 2** by

$$L_{uRb} \;=\; 10\log\left[(\gamma \cdot 10^{0{,}1L_b} \;-\; 10^{0{,}1L_a} + A_{rR}) \,/\, (\gamma - 10^{0{,}1D_R})\right], \tag{24a}$$

$$L_{lRb} \;=\; 10\log\left[(\gamma \cdot 10^{0{,}1L_b} \;-\; 10^{0{,}1L_a} - A_{rR}) \,/\, (\gamma - 10^{0{,}1D_R})\right] \tag{24b}$$

where

$$A_{rR} \;=\; \sqrt{A_1^2 + \gamma^2 \cdot A_2^2}\,. \tag{25}$$

For site 1 is valid

$L_{uRa} = L_{uRb} + D_R$ (26a) and $L_{lRa} = L_{lRb} + D_R$. (26b)

The resolution limits for the determination of the residual levels at site 2 and 1 are calculated by

$L_{rlRb} = 10\log\left[A_{rR} \,/\, (\gamma - 10^{0{,}1D_R})\right]$ (27a) and $L_{rlRa} = L_{rlRb} + D_R$. (27b)

To use all these relations for evaluation in a comfortable manner we implemented them into the measuring system by a further processing software. Input data are measurement time intervals as mentioned above, the measured L_x levels and the V_L-values (see eq. (1)).
This technique provides a convenient and flexible tool for measurements in the practice of environmental noise control.

4. EXAMPLE

The sound level L_{eq} of a continuously working 500 MW power plant was to be determined at the nearest margin of a residental area in 220 m distance to the station radiating with sufficient approximation as a whole like a point source. The residual noise coming from the traffic on a nearby major road and on the downtown roads was at least as intense as that from the power station. This is also valid during the night and then still if the wind goes from the source toward the immission site. The second measurement site was chosen in 320 m distance. By measuring during a very significantly dominating residual noise level the parameter D_R was determined for the L_{50} to be - 0,5 dB(A). To this result can be attributed a confidence interval $V_L \cong 0{,}3$ dB(A). The additional attenuation D_{12} (in eq. (7)) was calculated by

Figure 2: Sound pressure level and confidence limits at site 2 of superimposed plant and dominating traffic noise. The corresponding level diagrams for site 1 are shown in [10].

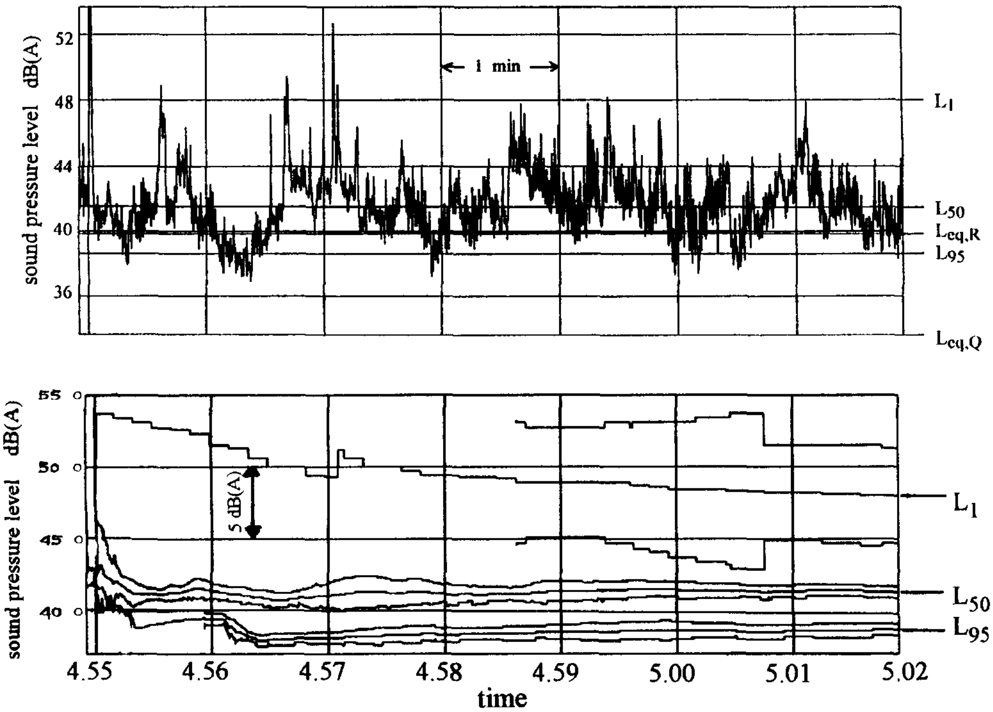

Table 1: Input values from measurement for the evaluation of the L_{eq} level of the power plant and of the residual noise.

	Time interval min	Level L_{50} dB(A)	Half width V_L of L_{50} dB(A)
1. measurement at site 2	7	40,1	0,4
Measurement at site 1	14	41,7	0,1
2. measurement at site 2	7	41,5	0,4

[2] to be 0,8 dB(A). The further input data are listed in table 1.

The output of the instant evaluation at site according to the series of equations (9) to (27 b) is listed in table 2.
According to the noise immission limits given by legislation and its ececutive regulations the plant should not exceed 40 dB(A) at the site 1 during night by its L_{eq}. As the upper confidence limit is 39,4 dB(A), *this condition is significantly fullfilled* in the sense of this procedure.

Table 2: Results of the evaluation starting from table 1

Power plant immission components			Residual noise components		
Levels, dB(A)	Site 1	Site 2	Levels, dB(A)	Site 1	Site 2
Leq,Q 1)	37,8	33,8	Leq,R 2)	39,4	39,9
Lu	39,4	35,3	Lu	40,5	41,0
Ll	35,4	31,3	Ll	37,9	38,4
Lu-Ll	4		Lu-Ll	2,6	
Dist. Leq,Q to its resol. limit	+ 3,6		Dist. Leq,R to its resol. limit	+ 5,4	
Dist. Leq,Q to Leq,R	-1,6	-6,1			

1) Identically to L_{Qa}, L_{Qb}. See eqs. (9), (10). 2) Identically to L_{Ra}, L_{Rb}. See eqs. (22), (23).

5. CONCLUSIONS

The online monitored percentile confidence limits enable to a *quality* controlled sound component level location and so its separation with a high resolution. This is achieved by only short term measurements, also in complex situations. The technique reported here is principally also applicable in the field of occupational noise exposure control or on sound transmission and damping of stochastically varying sound levels within buildings. This progress is, besides the method itself, also due to the high speed hardware (PC) and specific computer programs developed for the performance of the measurement and the subsequent final quick evaluation. As the experimental test results appear to have provided substantial proofs for its practical use, also due to its functionality, the method and technology presents itself for actual applications.

6. ACKNOWLEDGEMENT

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