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Microphone array based automated environmental noise measurement system

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ABSTRACT

State of the art environmental noise monitoring systems are based on digital signal processing. In general, they measure and store environmental noise levels, but also perform computation, spectral filtering, narrowband spectral analysis, evaluation of statistical indices, wave recordings, detection of noise events based on thresholds, and other similar tasks. Advances in processing power enabled application of smartphones for environmental noise measurements as well as the development of more sophisticated equipment capable of complex multi-channel digital signal processing in real time. This paper describes the development of three new measurement methods and their application in environmental noise monitoring system: 1) an automatic exclusion of uncorrelated noise events from measurements, 2) an automatic identification of the dominant noise source direction and 3) an automatic classification of the observed noise event. The implementation of these three options can reduce the need for human resources, ensuring lower costs and more reliable measurement results. Immision directivity is defined to determine the dominance of the noise source compared to the background noise. The suggested technical solution and new procedure was practically applied as a part of autonomous measurement and noise source classification system in the ambient noise investigation in a residential area.

1. Introduction

The environmental noise level depends on a combined contribution from all surrounding noise sources. A frequent task given to an acoustic laboratory is to determine the contribution of a specific noise source to the total environmental noise level. The problem arises when at the chosen measurement location the specific noise source generates noise levels which are comparable or even lower than residual noise levels. The contribution of main noise sources to the total noise level can be determined by extensive measurements under different operating conditions of individual sources. Different noise sources can operate simultaneously or at different time intervals while the duration of their operation is rarely deterministic. Therefore, the presence of personnel is always required to sample and record the operating conditions and the associated sound pressure levels.

The modelling of noise propagation together with environmental noise measurements provides a good estimation of the contribution of a specific noise source to the total noise level at a selected location. When using a modelling software, control measurements need to be performed, sound power levels of all noise sources as well as their operational schedules need to be determined, the geometry of the sources and receivers needs to be modelled, the topography of the terrain needs to be given, etc. Additionally, the uncertainty of ambient noise models can be quite large, especially when traffic and railway noise is modelled with different software packages and noise propagation models. A constant updating of software, technical standards and legislation adds to the variability of results at an administrative level. The accuracy of predicted noise levels in shielded or quiet areas is not very high, the noise maps fail to capture sounds that are less easy to predict, and above all, the dynamics of the sound environment is not included. Noise mapping can therefore be perceived as a tool for the extrapolation of measurement results to a larger area [1,2].

Continuous noise measurements are a credible source of information and can be used to validate noise maps [3]. Such measurements are expensive due to an expensive equipment, long measurement time and the need for educated staff. Those around shipyards, ship ports, airports, factories, mines and other large industrial areas, as well as in the city centres, usually require permanent installation of sound level measuring equipment. In such cases, the measurement equipment is left unattended and the recording of the environmental noise levels, including residual noise, is performed automatically. If operators are present during the noise measurements, residual noise events can be excluded from the measurements and noise properties, including the classification of noise sources and their directions can be recorded in

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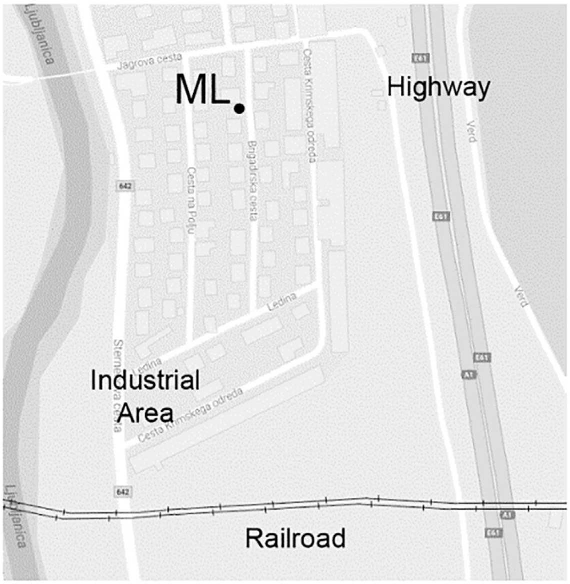

Fig. 1. An example of a situation during an environmental noise measurement.

situ. However, it is impractical and costly to assure the presence of certified personnel at the noise monitoring location over longer periods.

A typical example is depicted in Fig. 1. A measurement location in the residential area is marked with ML. There are three main noise sources; a highway, a railroad and an industrial area. In order to determine the contribution of a selected noise source to the total noise level at the measurement location ML, the presence of personnel is needed to classify the dominant noise into the three groups and record the instantaneous sound pressure level. Personnel classify noise events depending on the noise level threshold, which can be similar to the background noise level, the direction of the noise source and the subjective noise recognition capabilities. The classification is therefore based on the experience of the operator. In order to achieve an automation of the process, the equipment should therefore mimic the operator's activities during measurements. Microphone arrays are evidently considered as a tool for environmental noise measurements [4,5], but are only being used for spatial filtering of the signals and noise source localization.

An acoustic camera and its variations gained an important place in noise control in recent years. Its most noticeable advantage is to visualize the dominant noise source within the multitude of noise sources. The acoustic camera is not able to differ between sounds which come from the rear or the front. Therefore, at least two acoustic cameras would be needed to cover the viewing angle of 360° in a horizontal plane around the measurement microphone. Such devices are associated with high cost and work only with full resolution in real time. This consumes a lot of processing power which directly translates to shorter standby time of the autonomous measuring system.

A theoretical background and simulations are presented in this paper, which were used in the development of an automatic noise source classification system capable of monitoring multiple noise sources.

The system can perform automatic identification/classification of the prominent noise sources. It uses the acoustic signals recorded with a circular microphone array positioned in a horizontal plane. The incoming signals serve as input for the beamforming algorithm. The spatial information and the distribution of the incoming sound are then used to calculate immission directivity. How immission directivity is applied to calculate the contribution of a specific noise to the total noise level is also discussed and presented.

2. Environmental noise as a variable with random properties

Let us consider F noise sources allocated arbitrarily around the measurement point (*ML*). All considered noise sources are considered to be uncorrelated. Each noise source generates a sound pressure signal $p_i(t)$ at the measurement point ML, where i stands for the index of an individual noise source and p its corresponding sound pressure signal. Total RMS sound pressure squared p_{RMS}^2 associated with integration time constant τ is calculated as a sum of $p_{RMS,i}^2$ sound pressures generated by i-th noise source using Eq. (1). Integration time constantτ is usually set to 125 ms.

$$p_{RMS}^2(\tau) = \sum_{i=1}^{N} p_{RMS,i}^2(\tau) \tag{1}$$

In addition, a suitable measurement duration has to be chosen. This requires a careful balance between the stability and the repeatability on the one hand, and a sufficient degree of dynamics on the other hand. In an urban environment, short-term dynamics are mainly determined by passages of motorized vehicles. A suitable aggregation period depends on the traffic intensity, but 10–15 min is usually chosen as an appropriate monitoring period [1]. Consequently, an A weighted equivalent sound pressure level (L_{Aeq}) is used. L_{Aeq} is defined as shown in Eq. (2),

$$L_{Aeq}(\tau_2 - \tau_1) = 10log\left[\frac{1}{\tau_2-\tau_1}\int_{\tau_1}^{\tau_2}\frac{p_{RMS}^2(\tau)}{p_0^2}d\tau\right] \tag{2}$$

for continuous and in Eq. (3),

$$L_{Aeq}(T_M) = 10log\left[\frac{1}{T_M}\sum_{k=1}^{T_M}\frac{p_{RMS,k}^2}{p_0^2}\right] \tag{3}$$

for discrete sound pressure signals. Where τ_1 and τ_2 represent the starting and the ending time of the measurement respectively. T_M denotes the number of measured RMS sound pressure values. In practice, the integration time interval ($\tau_2 - \tau_1$) between 1 min to 1 h is chosen, while T_M consequently ranges from 480 to 28,800 values, depending on the sampling frequency. L_{Aeq} is a very important quantity, because the calculation of noise indicators L_d, L_e, L_n and L_{den} is explicitly based on it.

It is mathematically impossible to retrieve different values of L_{Aeq} corresponding to different noise sources from one signal. The use of a single microphone at the measurement location *ML* leads to an information deficit and only the information of the total sound pressure level $L_{ML}(\tau)$ can be obtained. However, we can take advantage of the 10 dBA signal to noise ratio (SNR) approximation (as suggested by different international standards, such as ISO 1996-2), together with the statistical property of simultaneity, as demonstrated in Fig. 2. If the noise source S_i generates a sound pressure level which is more than 10 dBA above a sound pressure level generated by all other noise sources, then the total sound pressure level equals the contribution of the noise source S_i. This approach is well known and daily applied in environmental noise measurements. Operators use the “pause” and “back erase” options on sound level meters (SLM) to record the sound pressure level of the specific noise. In order to automate this procedure, it is necessary to identify the dominant noise source within the multitude of noise sources. Eq. (4),

$$L_{Aeq,i} = 10log\left(\frac{1}{\sum_{j=1}^{E}(\tau_{i,j,2}-\tau_{i,j,1})}\left(\sum_{j=1}^{E}\left(\int_{\tau_{i,j,1}}^{\tau_{i,j,2}}\frac{p_{RMS}^2(\tau)}{p_0^2}d\tau\right)\right)\right) \tag{4}$$

can be used to calculate the A weighted equivalent noise level contributed to noise source S_i. Markers for the individual noise source S_i are determined by the start $\tau_{i,j,1}$ and the ending time $\tau_{i,j,2}$. The index i indicates the noise source, the index j the successive number of noise