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Estimation of the minimum measurement time interval in acoustic noise

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A B S T R A C T

The appropriate choice of the minimum measurement time interval is introduced for an accurate estimation of environmental noise indicators. The proposal is based on a bootstrap approach for the continuous estimation of measurement uncertainty in order to determine the statistical variability of the acquired sound pressure levels. Experimental results concerning the adoption of the proposed method regarding environmental noise from three different sources (road traffic, outdoor air conditioner fan motor and construction site) confirm the reliability of the proposal and its feasibility in evaluating the equivalent sound pressure level of an acoustic phenomenon using short-term indicators.

1. Introduction

One of today's most important environmental problems is noise pollution. In order to assess the acoustic environmental impact of new infrastructure or the compatibility of the existing noise with the maximum limits established by legislation [1], it is necessary to arrive at an appropriate calculation of the environmental noise equivalent continuous A-weighted sound pressure level. According to [2], the measurement should optimally be carried out continuously over the entire observation period. Such an approach is prohibitively costly in terms of time and money. In practice therefore, environmental noise indicators are estimated from several measurement time windows (episodes) randomly distributed throughout the observation period, during day, evening and night reference time.

Each measurement time interval has to contain representative values of noise pressure levels to accurately calculate equivalent sound pressure level L_{Aeq}. This is obtained by integrating and averaging the squared A-weighted sound pressure of fluctuating noise [3–6]. The actual form of the technical standards do not provide practical criteria for the choice of the temporal distribution of the samples, i.e. the number and duration of the measurement episodes. For example, ISO 1996-Part 2 states only "*to select the measurement time interval to cover all significant variations in sound emission and propagation. If the noise shows periodicity, the measurement time interval should cover an integer number of at least three periods. If continuous measurements over such a period cannot be made, measurement time intervals shall be chosen so that each one constitutes a part of the cycle, so that, together, they represent the complete cycle*". Unfortunately, this condition is generally not applicable for environmental noise where the acoustic signal is random.

Some surveys [7–9] show that the reliability of the estimate of environmental noise indicators depends largely on the time variability of the noise, so a sampling technique has to be chosen according to address this parameter.

Drawing on previous studies, the authors introduce an original method for choosing the minimum measurement time interval that takes into account the statistical variability of the acoustic phenomenon. The model may be adopted for the automatic determination of the measurement episodes, by lowering the sampling window necessary to estimate the short and/or long term indicators.

2. State of the art

The road traffic noise is one of the main sources of pollution, so the estimation of minimum measurement time interval represents an important research topic, to which many studies have been devoted.

In [10], with reference to 5 years of continuous noise measurements of $L_{Aeq,24h}$ carried out in Valencia (Spain), the appropriate period of measurement over a 24-h noise intervals in order to calculate the corresponding annual equivalent level has been investigated. The findings offer very useful information on traffic noise

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measurement techniques. In particular, the sampling strategy with a selection of at least 6 randomly chosen days provides an accurate representation of the annual equivalent noise level.

In [11] long term equivalent levels of road traffic noise acquired in Ladenburg, Germany, have been considered and different measurement approaches have been discussed. The author demonstrate that a sampling strategy of at least one week leads to the uncertainty of less than ±1 *dB* in noise equivalent levels.

Jagniatinskis and Fiks in [12] focus their attention on a one-year duration noise monitoring experiment in the town of Vilnius (Lithuania) near an arterial road with intensive road traffic. They observe that, under normal weather and source emission conditions, the lowest uncertainty values of L_{den} occur when a total measurement time of 7 consecutive days is considered.

In [13] the author determines the minimum time necessary for accurately measuring the hourly equivalent level of road traffic noise according to preset measurement uncertainty [14,15] on L_{Aeq}. Analogously, in [16–18] the authors find that the minimum measurement time interval should be calculated from the error associated with L_{Aeq} on the basis of various vehicle distributions. More specifically, by measuring over intervals of less than an hour, they find it is possible to have an accurate measurement of road traffic noise, within a predetermined uncertainty range for the hourly values of L_{Aeq}.

A different approach based on probability studies focuses on the determination of the minimum time for estimating a reliable value of L_{Aeq} drawing cases in which the probability density function of noise level is known theoretically or experimentally [19–21].

Some authors, such as Maruyama et al., address the issue of the minimum measurement time interval T to evaluate the equivalent sound pressure level L_{AeqT} of road traffic noise from the viewpoint of the reliability required for the estimation. In particular, in [22] they consider the influence of four kinds of traffic variables (traffic volume, average vehicle speed, percentage of heavy vehicles and the number of vehicle transits). In [23] they introduce two types of dynamic statistics: the mean time interval between two successive maximum A-weighted sound pressure levels observed during the reference measurement time interval and the mean recurrence time of the maximum A-weighted sound pressure level.

In [24], for the estimation of the traffic noise minimum measurement time interval in the city of Hamadan (West of Iran), the main roads are divided into 54 segments and 94 measuring stations are fixed. Field data obtained from 282 measurements, including 2 daily-hour and one nightly-hour measurements, show that 10-min interval measurement of equivalent sound pressure level is able to forecast the hourly values of L_{Aeq} in each station.

Jagniatinskis et al. in [25] suggest the replacement of full year measurement by choosing a shorter time interval using the idea of representative time interval that contains an appropriate amount of transportation noise events. In particular, they analyse the representative sample definition for the cases of road, aircraft and rail transport. In Lithuania, for example, a representative measurement time interval for annual urban traffic noise assessment, under normal weather conditions, is one week.

In [26] the authors focus their attention on the effectiveness of using short time span measurements to monitor or assess the acoustical environment. On the basis of data acquired in the high-rise residential areas of Hong Kong, they observe that short time interval results are much lower than the worst scenario of a site, but the energy-based Day–night level and Day–evening–night level are acceptable.

As a summary of the reported literature, most of the proposed approaches refer to the estimation of the minimum measurement time about long-term traffic noise indicator. The topic of the measurement of the short term equivalent sound pressure level, which may be independent from the previous knowledge (i.e. statistical distribution and/or main influence parameters) of the acoustic phenomenon, has not been sufficiently explored

3. The proposal

In order to determine the minimum measurement time interval for the estimation of the environmental noise, a data-driven sampling strategy is proposed, which takes into account the observed variability associated with measured sound pressure levels. In particular, the data variability is estimated by adopting the popular technique of the bootstrap [27], i.e. a statistical nonparametric resampling method which replicates the initial dataset, without any restrictions in terms of shape and properties of the statistical distributions under consideration.

In this proposal, the bootstrap technique has been adopted to determine the Confidence Interval (*CI*) of the short time statistic L_{Aeq}, once the desired Confidence Level (*CL*) has been chosen. In literature, some rules of thumb have been suggested both for the number of bootstrap samples and type of algorithm for *CI* calculation, such as the normal approximation (NORM), the t-student (T-STUD), the basic percentile (PER), the bias corrected percentile (CPER), and the bias corrected and accelerated percentile (BCA) methods [28–32].

Typically, values (m) at least equal to 1000 should be considered for *CI* calculation [33,34]. Moreover, as reported in [35], the CPER method has been revealed the most repeatable algorithm for determining the *CI* of the short-term statistic and consequently it has been implemented in this proposal. In particular, the CPER technique is a slight modification of the PER algorithm and it allows the mean of the transformed estimate to differ from the population mean: interval endpoints depend on the bias correction (z_0), that is calculated from the bootstrap sampling distribution.

As presented in Fig. 1, the proposed strategy hypothesizes a minimum acquisition time corresponding to the number (N) of sound pressure levels for assuring the statistical significance of the starting dataset. Consequently, the minimum measurement time T_{meas_min} (resulting from the proposed algorithm) is forced to be an integer multiple of the minimum acquisition time (as well as dependent from the frequency $1/T_{const}$ of the recorded data by the sound level meter).

The N A-weighted sound pressure levels L_t are considered to calculate the corresponding equivalent level according to the equation:

$$L_{Aeq} = 10Log\left(\frac{1}{N_{min}}\sum_{t=1}^{N_{min}} 10^{\frac{L_t}{10}}\right) \quad (1)$$

The *CI* of the above short term statistic (once the *CL* is fixed) is determined by applying the CPER bootstrap method and considering m bootstrap samples (resampling the L_t dataset). In order to take into account the random variability introduced by the bootstrap method, k repetitions of the *CI* calculation are suggested to determine the (mean) values for the interval width (ΔCI) and extremes (CI_{lower} and CI_{upper}).

According to the strategy, the introduced steps are repeated for calculating the *CI* information for each next acquisition time window as long as both the actual interval width and extremes show a data variability lower than the one observed in the previous windows. Furthermore, satisfaction of the following conditions (Eq. (2)) are considered as a stopping rule:

$$\left(\Delta \mathrm{CI}^{\mathrm{i}+1} < \Delta \mathrm{CI}^{\mathrm{i,updated}}\right)\mathrm{AND}\left(CI^{\mathrm{i}+1}_{\mathrm{lower}} > CI^{\mathrm{i,updated}}_{\mathrm{lower}}\right)\mathrm{AND}\left(CI^{\mathrm{i}+1}_{\mathrm{upper}} < CI^{\mathrm{i,updated}}_{\mathrm{upper}}\right) = true; i \geqslant 1 \quad (2)$$