Measurement 98 (2017) 237–242

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Innovative bootstrap approach for the estimation of minimum measurement time interval in road traffic noise evaluation

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ARTICLE INFO

Article history:
Received 29 July 2016
Received in revised form 15 November 2016
Accepted 3 December 2016
Available online 7 December 2016

Keywords:
Noise control
Measurement uncertainty
Measurement time interval
Statistical analysis
Real time systems
Bootstrap method

ABSTRACT

It is observed that in order to characterize the environmental noise in a site, during diurnal reference time (6–22 h) or nocturnal reference time (22–6 h), relatively at preset time window, observation period, a single value of the equivalent continuous A-weighted sound pressure level $L_{A,eq}$ is used. This value is determined by integrating and averaging the squared A-weighted sound pressure of fluctuating noise during the measurement time interval, in which there are representative values of acoustic event pressure levels: so it is very important accurately to select the suitable integration time. Such matter are highly relevant to the area of measuring environmental noise and this paper aims to present a statistical method, for determining the minimum measurement time interval for an accurate estimation of L_{Aeq}. The proposed algorithm, based on CPER bootstrap method, has been experimentally verified with real data obtained from road traffic noise measurement and it showed a very good stability. The methodology is suitable for upgrading the level meter firmware in order to have the real time information on the measurand uncertainty estimation and on the minimum measurement time interval.

1. Introduction

For the characterization of the environmental noise in a site, i.e. the acoustic environmental impact of new infrastructure [1,2] or the compatibility of the existing noise with the maximum limits established by the law [3], the ISO 1996-2 standard [4] proposes to estimate environmental noise indicators with sampling methods, in particular to carry out a measurement campaign composed of several measurement time windows distributed throughout a preset time interval, the observation period, during diurnal reference time (6–22 h) or nocturnal reference time (22–6 h), So, the choice of the minimum integration time, in which there are representative values of acoustic event pressure levels, for calculating accurately equivalent continuous A-weighted sound pressure level $L_{Aeq,}$ obtained by integrating and averaging the squared A-weighted sound pressure of fluctuating noise [5] during the measurement time interval [6–8], is a very relevant issue today.

Although continuous detection systems have been recently developed, the need for reducing the time and resources to be committed in the single site, in order to increase the number of the measurement positions and to improve the spatial survey significance, still remains. For this purpose, temporal sampling techniques are used, by which the long-term value of environmental noise is estimated on the basis of a series of data detected at preset time intervals. Some surveys [9–11] have shown that the reliability of this estimate depends significantly on the variability of the noise in time domain, so it is necessary that the sampling technique is chosen according to this parameter. Unfortunately the actual technical standards requires that the measurement time is enough to obtain a meaningful assessment of the sound phenomenon, without providing practical criteria for the choice of the temporal distribution of the samples. 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*" [4]. In practice, however, this condition is generally not applicable for environmental noise that is a not periodic acoustic signal but it has a random trend in time domain.

2. State of the art

In the following, the main research topics in the area of the determination of the minimum measurement time interval for evaluating the sound pressure level of road traffic noise are highlighted.

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http://dx.doi.org/10.1016/j.measurement.2016.12.008
0263-2241/

Skarlatos et al. in [12–14] proposed a probabilistic method for determining the minimum time of observation for estimate L_{Aeq} in cases in which the probability density function of noise level is known.

De Donato [15] discussed a minimum time necessary for measuring the hourly equivalent level of road traffic noise with a designated measurement uncertainty [16,17] on L_{Aeq} and showed that minimum measurement time interval could be obtained from the expression of error associated with L_{Aeq} according to various vehicle distributions. In particular, the author stated that it is possible to have a correct characterization of road traffic noise, within a predetermined uncertainty range [18–20] hourly $L_{Aeq,}$ by measuring over times shorter than an hour.

Maruyama et al. [21] determined the minimum measurement time for the estimation of the equivalent sound pressure level during measurement time interval T, $L_{Aeq,T}$, of road traffic noise from the number of vehicle transits through a mathematical model. The authors focused on the influence of four kinds of traffic variables exerted on $L_{Aeq,T}$: traffic volume, average vehicle speed, percentage of heavy vehicles and the number of vehicle transits. According to the results obtained with the proposed model, if the time interval between about 70 vehicles passing the observation point placed at $d_0 = 25–50$ m from the road was selected as the measurement time interval T, the measured $L_{Aeq,T}$ fall within ±1 dBA around the long time $L_{Aeq,T}$ with the reliability of 75% or more, even though traffic conditions varied. If the time interval corresponding to about 170 vehicle passing was selected as the measurement time interval T, the errors of measured $L_{Aeq,T}$ was within ±1 dBA with the increased reliability of 90% or more. If the probability distribution of the number of vehicle transits was approximated by the normal distribution, on the one hand, the reliability of estimation of $L_{\mathrm{Aeq},T}$ was improved to 95.5% and 99.7% for the same conditions as those mentioned above, respectively.

The same authors in [22] addressed the issue of minimum measurement time interval to estimate a sound pressure level of road traffic noise with a designated reliability using two types of dynamic statistics. In this case, they considered variations in the noise emission from passing vehicles and they observed that if the traffic volume (Q) was about 740–820 vehicles/h, then:

- without considering the percentage of heavy vehicles, in order to obtain $L_{Aeq,T}$ within the permissible error of ±1 dBA and a reliability of 75% or more, time interval (T) should be as long as the time interval for the mean recurrence time interval, i.e. a statistic quantity that represents the time interval from the moment when the front of n successive vehicles passes by the observation point to the moment when the front of the following n vehicles reach the same point driving the same speed while maintaining minimum allowable distance between two successive vehicles;
- regardless of the percentage of heavy vehicles, in order to obtain $L_{Aeq,T}$ within the permissible error of ± 1 dBA and a reliability of 90% or more, time interval (T) should be about 2 times as long as the time interval for the mean recurrence time interval;

If the traffic volume (Q) was about 240–340 vehicles/h, then:

- regardless of the percentage of heavy vehicles, in order to obtain measurement values with a reliability of 75%, time interval (T) should be about 1,5 times as long as the time interval for the mean recurrence time interval;
- regardless of the percentage of heavy vehicles, in order to obtain measurement values with a 90% reliability, time interval (T) should be about 3 times as long as the time interval for the mean recurrence time interval.

3. The proposal

For determining the minimum measurement time interval necessary to an accurate estimate of the equivalent sound pressure level of environmental noise, a data-driven sampling strategy is proposed, which takes into account the observed variability associated to the measured sound pressure levels.

More in details, the data variability is estimated by adopting the popular technique of the non-parametric bootstrap [23], that is a statistical resampling method, which replicates the initial dataset, without any restrictions in terms of shape and properties of the statistical distributions under consideration. In other words, new (m) data sets (named the bootstrap samples) are replicated by sampling from the initial data. By means this resampling procedure, these distributions can be considered as approximations of the true distributions of the estimations, and thus a good approximation of the distribution of relevant statistics. As an example, Fig. 1 depicts the non-parametric bootstrap method when it is applied to the estimation of the mean and the corresponding standard deviation.

In the context of interest, the non-parametric 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 proposed 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 [24–28]. Typically, values (m) at least equal to 1000 should be considered for *CI* calculation [29,30]. Moreover, as reported in [31,32], the CPER method has been revealed the most reliable algorithm for determining the *CI* of the long-term statistic about the road traffic noise and consequently it has been implemented in this proposal.

The bias corrected percentile bootstrap method allows the mean of the transformed estimate to differ from the population mean and corresponding confidence interval endpoints depend on one number z_0 (bias correction) calculated from the bootstrap sampling distribution [24–26].

The proposal strategy postulates a minimum acquisition time corresponding to the minimum number (N_{min}) of sound pressure levels for assuring the statistical significance of the starting dataset (typically some hundreds dimensionality should be considered). The minimum measurement time is forced to be an integer multiple of the chosen minimum acquisition time T_{acq} (as well as dependent from the time history logging of the sound level meter).

The N_{min} A-weighted sound pressure levels L_t are considered to calculate the corresponding equivalent level according to Eq. (1):

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

The *CI* of the above short time 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}).

The proposed strategy for determining the minimum measurement time is schemed in Fig. 2: the above mentioned steps (for calculating the *CI* information) are continuously applied to consecutive acquisition time windows (next to the starting point), as long as both the actual interval width and extremes show a data variability lower than the one observed in the previous windows.