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Low frequency noise and infrasound: A new method to determine the *specific sound* from the *total sound*; a plausible statistical algorithm for use in Legal Noise Assessment

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Abstract

All impacts of noise are presented within a complex acoustic environment, sometimes from a single source (e.g., a sole piece of equipment or an industrial site) or from multiple sources. It is well known that any sound measurement - whether indoors or out –is registered by SLM and usually identified as the *total sound*. The issue here is that there is not always a simple way to distinguish a *specific sound* from the *total sound*, and it is impossible to conduct an *fft* analysis and "eliminate" its spectrum in the signal recorded at the receiver position. In this work, the author proposes a new method of employing statistical tools. Applying this concept of eliminating unwanted sound levels (low frequencies from traffic noise or infrasound of the environment) will be the technique used to evaluate noise under ISO 1996 standards, the accepted procedure for legal evaluations.

Key words: low frequency noise, infrasound, guidelines, noise disturbance, acoustical statistics.

Низкочастотный шум и инфразвук: новый метод определения конкретного звука из общего звука. Достоверный статистический алгоритм для использования в правовой оценке шума

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Аннотация

Все воздействия шума представлены в сложной акустической среде, иногда от одного источника (отдельная часть оборудования, промышленная площадка) или от нескольких источников. Хорошо известно, что любое измерение звука – будь то внутри помещения или снаружи – регистрируется шумомером и обычно определяется как общий звук. Проблема здесь в том, что не всегда есть простой способ отличить конкретный звук от общего звука, и невозможно провести анализ БПФ и "исключить" его спектр в сигнале, записанном в расположении приемника. В данной работе предлагается новый метод использования статистических инструментов. Применение данной концепции устранения нежелательных уровней шума (низкие частоты от шума дорожного движения или инфразвука окружающей среды) будет являться методом, используемым для оценки шума в соответствии с концепциями ISO 1996 года, который является достоверной процедурой для правовых оценок.

Ключевые слова: *низкочастотный шум, инфразвук, методическое руководство, раздражающее воздействие шума, акустическая статистика.*

Introduction

One of the most important challenges in the field of environmental acoustics, specifically in sound measurement, is determining the lowest possible uncertainty in the sound level which comes from a specific source of noise, taking into account most often the

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receiver is not in an acoustic environment with a single source. That means that it is immersed in a complex environment with many noise-emitting sources.

Over time, many methods have been proposed to "isolate" the specific source of noise to be analyzed, some having complex solutions such as filtering the noise of interest in the frequency spectrum; however, this leads to an energy loss of the resulting signal. The other methods suggest higher order statistical algorithms.

In this article the author proposes a simple comprehension algorithm – it was developed in 2011- which consists of expanding the concept of anomalous events, statistically known as "outliers," to eliminate sound levels exceeding a certain percentile sound level, using the time-history noise vector in order to obtain a new vector containing only the sound values within the sound level that specifically interest us. In summary, we mean to obtain the level of the *specific sound* from the *total sound*.

1. Analysis of the environmental-noise measurements according to ISO 1996

In the versions previous to 2016 of the ISO 1996 standards, only the *total sound* and *specific sound* were defined, and procedures were not directly recommended which took into account into account how the *specific sound* could be distinguished from the *total sound*

For years, acousticians have pondered how to eliminate unwanted sound, which is the sound which doesn’t belong to the noise source of interest. Some of the most common practices have been:

- **a.** To turn on/off sound sources, though this is impossible to do on industrial sites or with machines under mandatory continuous employment (e.g., power stations, pump/compressor stations, etc.).
- **b.** To conduct measurement on holidays, taking advantage of low levels of urban noise and suspended traffic density.

Now, the last actualization of the two parts of ISO 1996 Standard was established by a group of informative instructions, one of which has been resolved by this article’s authors previously [1]: “*Record the time history of the noise to be measured and use statistical or other methods to exclude unwanted sound*” [2; p. 41].

2. Some background of statistical tools

Here, some statistical definitions (ones useful for the problem that the author wants to solve) are explained to understand the development of the proposed algorithm.

2.1. Log-normal distribution

It is a common mistake to consider that the sound level has a statistical "normal distribution;" in reality, however, its distribution is of the logarithmic type [3] expressed in decibels. This is easy to understand because the equivalent continuous sound pressure level (ECSPL) is never equal to the means one. Then, statistically speaking, expressing the standard distribution of an environmental noise measurement as a *log-normal distribution* is the correct term. There is a slight difference between the two means, but delving into that is not the object of this article. The author wants to clarify that a measurement of environmental noise has a statistical distribution of the "log-normal" type [4].

2.2. Outliers removal

The simplest procedure, statistically speaking, to eliminate anomalous events is to remove the outliers and to not consider those sound events which do not belong to the sound that is of specific interest. There are a number of methods and algorithms to remove the outliers [5]: for this particular procedure, generating and separating a vector with the *specific sound* noise from the vector containing the *total sound* data will be considered a threshold value from which all the noise levels that exceed it (considered "outliers"). This threshold will be defined by a percentile value. Other authors (in the field of physics or other sciences) use the same procedure [6], but instead of deeming it "outlier removal", they often use other synonymous terms such as "spikes removal", "removal of spurious", etc.

2.3. Noise data smoothing

Another useful statistical tool is to "smooth" the measurement, which is a technique typically used to remove noise from signals. The resulting vector of eliminating the anomalous events (the outliers) from the vector that contains the time-history of the *total sound* will contain a "smoothed signal" (all data belonging to the *specific sound* levels).

2.4. Bootstrapping and recursive partitioning

For this specific case in which a simplified method is proposed to estimate the level of the *specific sound*, eliminating the outliers and obtaining a smoothing measurement, it is not necessary to use recursive tools or bootstrapping tools.

2.5. Time history filtering

The only filtering used is to remove ("extracting") the outliers which exceed a threshold. There is no frequency filtering; only the signal that is above a threshold percentile value is "filtered." Therefore, what is being filtered is the information contained in the time-history vector of the *total sound*.

3. Real noise sound level measurements

In this section, results of real measurements will be presented, with some explanations of the SLM and computational programs used.

3.1. Instrumentation

The instrumentation that one has to use in order to apply the method proposed here is very important because, in addition to the fact that the SLM has to be a high-quality analyzer, it is necessary to have a data logger capacity. The author uses CESVA® instruments (from Barcelona), the SC420® model, and this equipment records into a miniSD card the following parameters for each 125 ms: time history, $L_{A,T}$, $L_{C,T}$, $L_{Z,T}$, one-third-octave band form 10 Hz to 20 kHz, and other descriptors. It means 8 noise samples each second for each parameter.

3.1.1. Files size and quantity of data

To get an idea of the size of the spreadsheets files in the Excel® format, the next table shows the quantity of rows and columns for various measurement times.

Table 1
Quantity of raw data and size of files according to record time (ref. dB 20 μPa)

Item	**Total interval time**	**Rows**	**Columns**	**Total individual noise data**	**File size**
1	24 hours	691,200	47	32,486,400	189 Mb
2	1 hour	28,800	47	1,353,600	9,8 Mb
3	20 minutes	9,600	47	451,200	3,2 Mb

In the previous table, one can see that a 24-hour file has more than 32 million of individual noise data.

3.1.2. Conducting measurements of medium and long duration

One issue to consider in this kind of measurements is the power energy. So the author used big dry batteries, solar panels to charge it, and a DC voltage regulator to power the instruments. The following pictures show different scenarios.

Fig. 1. Pictures of medium and long term outdoor and indoor monitoring stations

3.2. Time-history vs. log-normal distribution

The sound level will be represented with dots (one dot for each ECSPL registered in sub-intervals of 125 ms, with an interval of 60 minutes long) instead of "seeing" it as a continuous line. All measurements were done on the sidewalks of the residential homes in front of a paper mill business

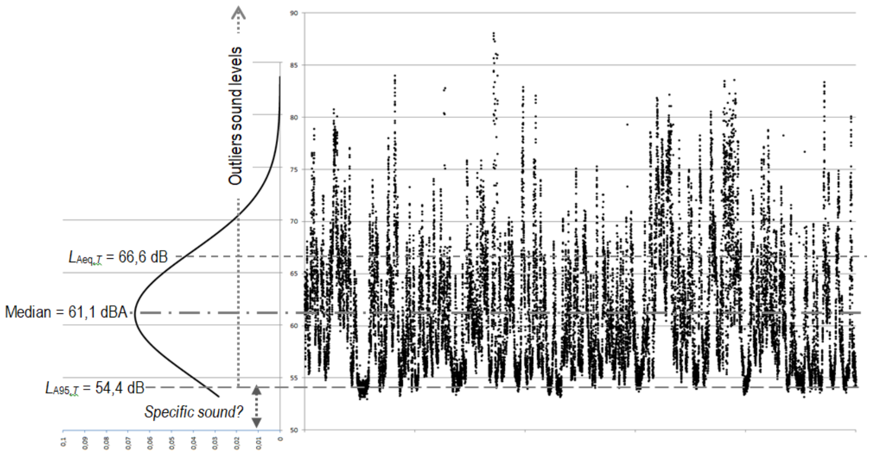

Fig. 2. Total sound time history and its log-normal distribution. Point #1

In the above figure, it can be observed that there is a small concentration of sound levels below 55 dBA, distributed throughout the 60-minute interval measurement. A similar concept can be found in other works, meaning it can be "seen" in another way [7].

3.3. Percentile sound level

The following table summarizes the noise descriptors of the measurement shown in Fig. 2 of the whole 60-minute interval measurement. For the percentile level calculation, the "percentile" function included in Excel® was used on L_{A125ms} data.

Table 2
Noise descriptors of the *total sound* level at point #1 (ref. dB 20 μPa)

$L_{\text{Aeq},T}$	$L_{\text{Ceq},T}$	$L_{\text{Zeq},T}$	$L_{\text{A01},T}$	$L_{\text{A05},T}$	$L_{\text{A10},T}$	$L_{\text{A50},T}$	$L_{\text{A90},T}$	$L_{\text{A95},T}$	$L_{\text{A99},T}$
66.6	77.2	78.9	78.1	72.9	69.1	59.8	54.8	54.4	53.9

In the table above, one can see that the noise levels are below 55 dBA, down from the 90th percentile value. A specific macro was written with Excel® spreadsheet to process the thousands' values in order to obtain one single value for each of these noise descriptors.

3.4. Estimating the specific sound, either $L_{A90,T}$ or $L_{A95,T}$ levels

The easy way of estimating the possible sound pressure level at these measurement points, according to some Standards or Legal references, is to assume that the $L_{\text{A90},T}$ or $L_{\text{A95},T}$ are the "specific sound level." The problem with this assumption is that no one can know the actual sound spectrum (or the $L_{\text{Ceq},T}$) because it doesn't have the complete vector of the *specific sound* level information, just one single "representative" value.

Table 3
Estimating the *specific sound* level, considering only the *total sound* at point #1 (ref. dB 20 μPa)

	***Total sound* level measured ≡ $L_{\text{Aeq},T}$**	**Estimated #1 *specific sound* level ≈ $L_{\text{A90},T}$**	**Estimated #2 *specific sound* level ≈ $L_{\text{A95},T}$**
$L_{\text{Aeq},T}$	66.6	54.8	54.4
$L_{\text{Ceq},T}$	77.2	unknown	unknown
$L_{\text{Zeq},T}$	78.9	unknown	unknown

4. The problem of using a single percentile level to represent $L_{Aeq,T}$

The question is, in this assumption, which of these two values should be chosen as the representative of *specific sound*? Moreover, how should one know the low frequency sound level under this assumption? It is impossible to know.

5. Algorithm to eliminate outlier sound levels

The algorithm is: using a vector containing the *total sound* level values with the time history measurement of each 125 ms ECSPL, has to make a new vector containing only the noise level which is less than a threshold value (e.g. a percentile level). This new vector will show the *specific sound* time-history values.

Considering that the noise source(s) has a steady sound level emission, the procedures included in this algorithm are:

- **a.** Procedure # 1: the vector has one row for each 125 ms ECSPL belonging to the spectrum of the *total sound* level, containing $L_{\text{A},T}$, $L_{\text{C},T}$, $L_{\text{Z},T}$, one-third-octave band form 10 Hz to 20 kHz, and other descriptors.
- **b.** Procedure # 2: the interval measurement time is at least 20 minutes in length.
- **c.** Procedure # 3: a threshold sound level close to $L_{\text{A90},T}$ or $L_{\text{A95},T}$ is established in order to eliminate outliers.

d. Procedure # 4: a new vector containing only the raw data of *specific sound* is obtained, meaning one row for each 125 ms ECSPL below the threshold percentile value, containing $L_{A,T}$, $L_{C,T}$, $L_{Z,T}$, one-third-octave band forming 10 Hz to 20 kHz, etc.

e. Procedure # 5: the new valid vector is processed to obtain the ECSPL spectrum, $L_{Aeq,T}$ and its descriptors, all belonging to *specific sound* level.

The previous procedures were adapted from Pierce Criterion [8]. Similar outlier concepts exist [7, 9, 10, 11], but not the same as the author has used here.

The algorithm was written with Visual Basic® (Microsoft Excel®). The macro is intended to calculate automatically, total all measurements made at the same point and issue results including the uncertain value of one single *specific sound* equivalent level.

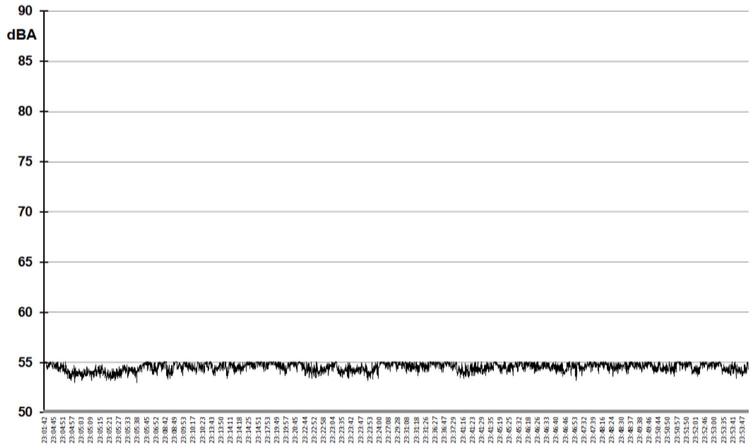

Fig. 3. Time-history of the *specific sound* smoothed signal. Point #1

In figure 3, one can see the noise levels below 55 dBA, which correlates with the *specific sound* level, after the outliers' removal above 55.1 dBA. Some similar concepts are used, though in other ways with different data [12, 13].

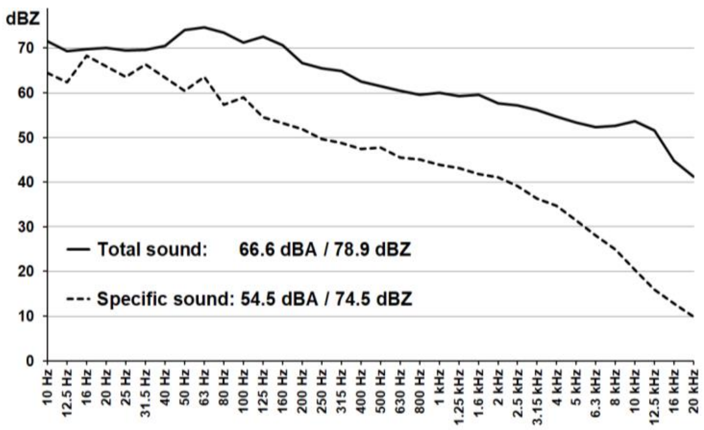

Fig. 4. Comparison of the spectrums: *Total sound* vs. *specific sound*. Point #1

The above graph shows (simultaneously) a comparison of the sound level spectrums of a *specific sound* from its corresponding *total sound*, where it can be seen how, after application of the proposed algorithm (written with Visual Basic®), the *specific sound* spectrum is "clean" of any outliers or unwanted sound. It appears that tonal sounds in low frequency and infrasound bands were masked by turbulent atmospheric and traffic noise.

6. Statistical validation of the proposed algorithm

In order to achieve an objective analysis, some statistical tools had to be used, such as Deviation and Variance calculated with 95% accuracy (functions included in Excel®).

Table 4
Statistical analysis of *total sound* vs. *specific sound* at point #1

Classification	Deviation	Variance	Observation
$L_{\mathrm{Aeq},T}$ Total sound	6.104	35.153	60 minutes
$L_{\mathrm{Aeq},T}$ Specific sound	0.415	0.172	7.5 minutes
Difference	-5.689	-34.981	

The benefits of applying the proposed algorithm can be seen in the above table because of the Deviation reduction. Another interesting point to analyze in noise level behavior is the noise level "reduction," due to outlier removal, as one can see in table 5, where the real noise reduction is shown in 4.4 dBZ (around to 138% less acoustic energy). The time interval of the *specific sound* file (containing the $L_{\mathrm{A},T}$, $L_{\mathrm{C},T}$, $L_{\mathrm{Z},T}$, one-third-octave band form 10 Hz to 20 kHz, etc.) is about 7.5 minutes, containing the smoothed measurement below the chosen threshold percentile value.

Table 5
Comparison of *total sound* vs. *specific sound* levels at point #1 (ref. dB 20 μPa)

Classification	$L_{\mathrm{Aeq},T}$	$L_{\mathrm{Ceq},T}$	$L_{\mathrm{Zeq},T}$
Total sound	66.6	77.2	78.9
Specific sound	54.5	70.1	74.5
Difference	-12.1	-7.1	**-4.4**

An inexperienced person, or an acoustician without proper training, would give the sound level measured by the SLM as valid, and therefore, erroneously communicate that the *total sound*" is the real noise emission of the noise source under consideration. But by applying this algorithm with outlier-removal criterion, one can estimate the *specific sound* level whiting a valid statistic interval. Table 6, unlike Table 2, resumes all noise descriptors which belong to the *specific sound* vector; for the percentile level calculation, the "percentile" function included in Excel® was used on L_{A125ms} resulting data.

Table 6
Noise descriptors of *specific sound* level at point #1 (ref. dB 20 μPa)

$L_{\mathrm{Aeq},T}$	$L_{\mathrm{Ceq},T}$	$L_{\mathrm{Zeq},T}$	$L_{\mathrm{A01},T}$	$L_{\mathrm{A05},T}$	$L_{\mathrm{A10},T}$	$L_{\mathrm{A50},T}$	$L_{\mathrm{A90},T}$	$L_{\mathrm{A95},T}$	$L_{\mathrm{A99},T}$
54.5	70.1	74.5	55.1	55.1	55.0	54.6	53.9	53.8	53.5

7. Determining the assessment of the audibility of tones in low frequency noise

In this article, the author presented a different view of statistical procedures that can be applied in environmental noise measurements, a useful tool in understanding how to determine the *specific sound* from a *total sound* measurement only when the noise emissions are well known and there is a steady, relatively stationary behavior.

Figure 5 shows that when outliers are removed from the *total sound* vector, the real *specific sound* level in the low frequencies band shows relevance, and the prominent tones contained in the spectrum can be found with less certainty (6 dB not 2.4 dB) on 63 Hz one-third-octave band (clarifying that in Peru, the frequency of the electric power system is 60 Hz -as in the US- and because of this, the prominent tone is presented at that frequency). It is also possible to determine the presence of a small discrete tone in infrasound, as in this case where the frequency of 16 Hz is in the one-third-octave band.

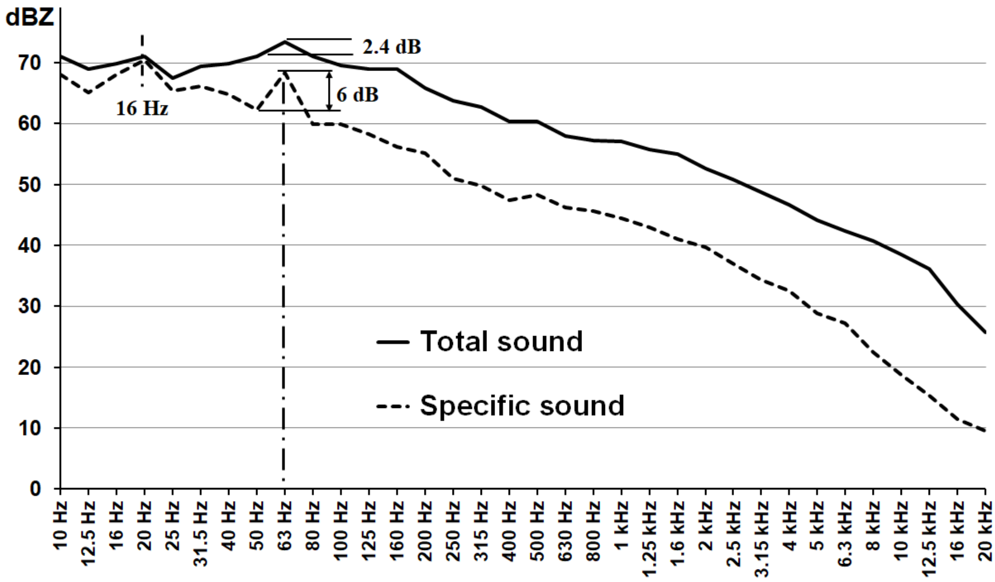

Fig. 5. Comparison of the spectrums: *Total sound* vs. *specific sound*. Point #2

According to ISO 1996-2:2017 Annex K "(…) [2], *to determine the presence a discrete-frequency spectral component (tone) typically compares the time-average SPL in some one-third-octave band with the time-average sound pressure levels in the adjacent two one-third-octave bands*," it is easier to see after applying this procedure and possible to "highlight" a discreet or prominent tone in the *specific sound* vector, which is "inside" the *total sound*, and impossible to evaluate it in the case of having just a single measurement.

Conclusion

For obvious reasons of space and time, it is not possible to show the source code of the computational processes. The purpose of this article is to submit to the acoustician community that it is possible to achieve a standardized method, in the sense that a procedure that could be agreed between specialists, and have a "universal" computer program to determine the *specific sound* contained in a vector with the *total sound*. At least the Criterion transcript here could be a plausible solution to be taken into account as a support tool in legal matters, since evaluating noise disturbance either under ISO 1996 [2, 14-16] or Legal Standards, with as little uncertainty as possible, is a problem throughout the world.

The author's purpose and intent is to transfer his heuristic knowledge in using this procedure for more than seven years in dozens of different geographical scenarios (urban, rural, mountain, tundra, industrial) in several countries and to introduce this technical discussion to acousticians from other countries with similar geographic assets. This algorithm was developed because a possible solution had to be presented to solve annoying noise problems, such as acoustic emissions emanating from gas pipelines or compressor or pumping stations from Peruvian Natural Gas facilities to like facilities in Russia, Australia and Canada.

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References

1. Montano W.A. (2011) Low frequency propagation in Amazonian rainforest (in Spanish). Acoustical Regional Meeting AdAA-AUA. Uruguay.
2. ISO 1996-2:2017 Acoustics - Description, measurement and assessment of environmental noise - Part 2: Determination of sound pressure levels.
3. Heyde C.C. (1963) On a Property of the Lognormal Distribution. The Australian National University, available at: https://www.researchgate.net/publication/226473183_On_a_Property_of_the_Lognormal_Distribution
4. Paviotti M., Kephalopoulos S. (2008) Expected mean in an environmental noise measurement and its related uncertainty. Acoustics'08 Paris. Euronoise, available at: http://webistem.com/acoustics2008/acoustics2008/cd1/data/articles/002849.pdf
5. Ben-Gal I. (2005) Outlier detection. Department of Industrial Engineering Tel-Aviv University. Israel, available at: http://www.eng.tau.ac.il/~bengal/outlier.pdf
6. Priora M.K. Colin M.E.G.D. (2017) Quantifying the impact of uncertainty on sonar performance predictions. UACE2017 - 4th Underwater Acoustics Conference and Exhibition (page 229), available at: http://www.uaconferences.org/
7. Russo D. (2015) Outlier Detection for the Evaluation of the Measurement Uncertainty of Environmental Acoustic Noise. IEEE Transactions on Instrumentation and Measurement, available at: https://scholar.google.com.pk/citations?user=4SLyhD8AAAAJ&hl=zh-CN
8. Ross S.M. (2003) Peirce's criterion for the elimination of suspect experimental data. Journal of Engineering Technology. University of New Haven, available at: https://classes.engineering.wustl.edu/2009/fall/che473/handouts/OutlierRejection.pdf
9. Smith M. Chiles S. (2012) Analysis techniques for wind farm sound level measurements. URS, Christchurch, New Zealand. Acoustic Australia magazine, available at: https://www.acoustics.asn.au/journal/2012/2012_40_1_Smith.pdf
10. Maijala P. (2014) A measurement-based statistical model to evaluate uncertainty in long-range noise assessments. Tampere University of Technology, available at: https://tutcris.tut.fi/portal/en/publications/a-measurementbased-statistical-model-to-evaluate-uncertainty-in-longrange-noise-assessments(3db2db94-5f43-4c43-b991-2350bf0c3927)/export.html
11. Gerges S. Dias R. Gerges R. (2016) Detection and Contribution of Outliers for Subjective Evaluation of Sound. UFSC, Brazil, available at: https://www.researchgate.net/publication/312076531_Detection_and_Contribution_of_Outliers_for_Subjective_Evaluation_of_Sound
12. Rim J. (2017) Introducing new scaled algorithms for improved outlier detection. available at: https://www.datadoghq.com/blog/service-map/
13. Lee H. (2015) Outlier detection in Datadog: A look at the algorithms, available at: https://www.datadoghq.com/blog/outlier-detection-algorithms-at-datadog/
14. ISO 1996-1:2003 Acoustics - Description, measurement and assessment of environmental noise - Part 1: Basic quantities and assessment procedures

15. ISO 1996-1:2016 Acoustics - Description, measurement and assessment of environmental noise - Part 1: Basic quantities and assessment procedures

16. ISO 1996-2:2007 Acoustics - Description, measurement and assessment of environmental noise - Part 2: Determination of environmental noise levels

17. Montano W.A. (2018) "Low frequency noise propagation in small Andean Peruvian cities". 25th ICSV Hiroshima.

18. Ruggiero A. Russo D. Sommella P. (2016) Determining environmental noise measurement uncertainty in the context of the Italian legislative framework. Elsevier magazine, available at: https://scholar.google.com.pk/citations?user=4SLyhD8AAAAJ&hl=zh-CN

19. Russo D. (2016) Innovative procedure for measurement uncertainty evaluation of environmental noise accounting for sound pressure variability. Doctoral Thesis. Italy, available at: http://elea.unisa.it/handle/10556/2574