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# Continuous monitoring of wind turbine noise

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## Summary

This paper presents the specificities and results of a cost-effective continuous monitoring system that was designed specifically for wind turbine noise analysis. The system utilizes Class 1 sound level meters, which are synchronized with other data sources such as audio/video recordings and meteorological data from local stations. The results are published on a web platform in near real-time, allowing for the identification of specific noise events and the automatic control of relevant parameters. The system can detect tonal characteristics using the ISO/TS 20065:2022 method and amplitude modulation, both of which are factors typically associated with wind turbine noise discomfort.

## 1. Introduction

This article presents the considered constraints, and their basis, and associated specific features for the development of the continuous noise monitoring system for wind farms, based essentially on sound levels, partly already developed and partly under development, by SCHIU in Portugal.

The development of this system aimed at wind farms (wind turbine noise) is associated with the growing interest of the technical acoustics community, and others, regarding this topic (see, for example, Vitor Rosão 2021).

It is clarified that the essential objective of this monitoring system is to characterise the so-called incident noise [non-consideration of possible sound reflections at the receiving point; see Directive 2002/49/EC and ISO 1996 (part 1: 2016; Part 2: 2017)] coming from a wind farm (wind turbine noise), perceived, outside, next to noise-sensitive receivers (in Portugal it is usual to define a noise-sensitive receiver by: "*the building house, school, hospital or similar or leisure space, with human use*").

The following conditions and the following associated aspects are highlighted and listed, which will serve as the basis for naming the subsequent chapters:

- A continuous noise monitoring system, based on the recording of sound levels, and which is intended to operate autonomously, without human presence, needs to have some form of control of which noise sources are at the origin of the sound levels that are being recorded, otherwise higher sound levels may be detected that do not originate from the noise source of interest. In the development of this system, 3 complementary ways were considered that help to detect, without human presence in real time, which sound levels are and are not associated with the source of noise in question:

    1. Audio/video recording in the measurement area, which allows a posteriori human or other analysis to try to distinguish "audibly" and/or "visually", the type of noise source that is generating the recorded sound levels.

    2. Synchronised recording of parameters other than sound levels, but which may have an influence on sound levels (from source noise or background noise), namely wind speed and direction (ideally through systems that do not generate "extra" sound levels"; an ultrasound-based system was used, with no moving parts) and rainfall, but also other typically relevant meteorological data, namely air temperature and humidity.

    3. Synchronised recording of sound levels, audio and video, in a location other than near to the receivers under analysis, in particular close to the noise source (in this case close to the wind turbine, or wind turbines) with greater influence on the sound levels perceived at the receiving point, to associate any variations in the sound levels of the noise source in question with the variation in sound levels at the receiver point (if the receiver is very close to the source, only one measurement point may be sufficient).

- One of the objectives of the continuous monitoring system developed, is to obtain results that can be used to verify compliance or non-compliance with certain technical acoustic requirements. The developed system is considering, for now, the following requirements and possibilities:

    4. Legal requirements (Portugal), in particular the following aspects:

        i. Limit values, parameters used and reference periods.

        ii. Noise Rating Level.

        iii. Tonal characteristics.

        iv. Impulsive characteristics.

        v. Long term average (see chapter "5.1 Limit values, parameters used and reference periods").

    5. Possibility of other requirements, in particular:

        i. Other frequency weightings.

        ii. Other tonal characteristics methods.

iii. Other impulsive characteristics methods.

iv. Other Amplitude Modulation methods.

Figure 1 shows the general aspect of the main page of the continuous monitoring system platform developed so far.

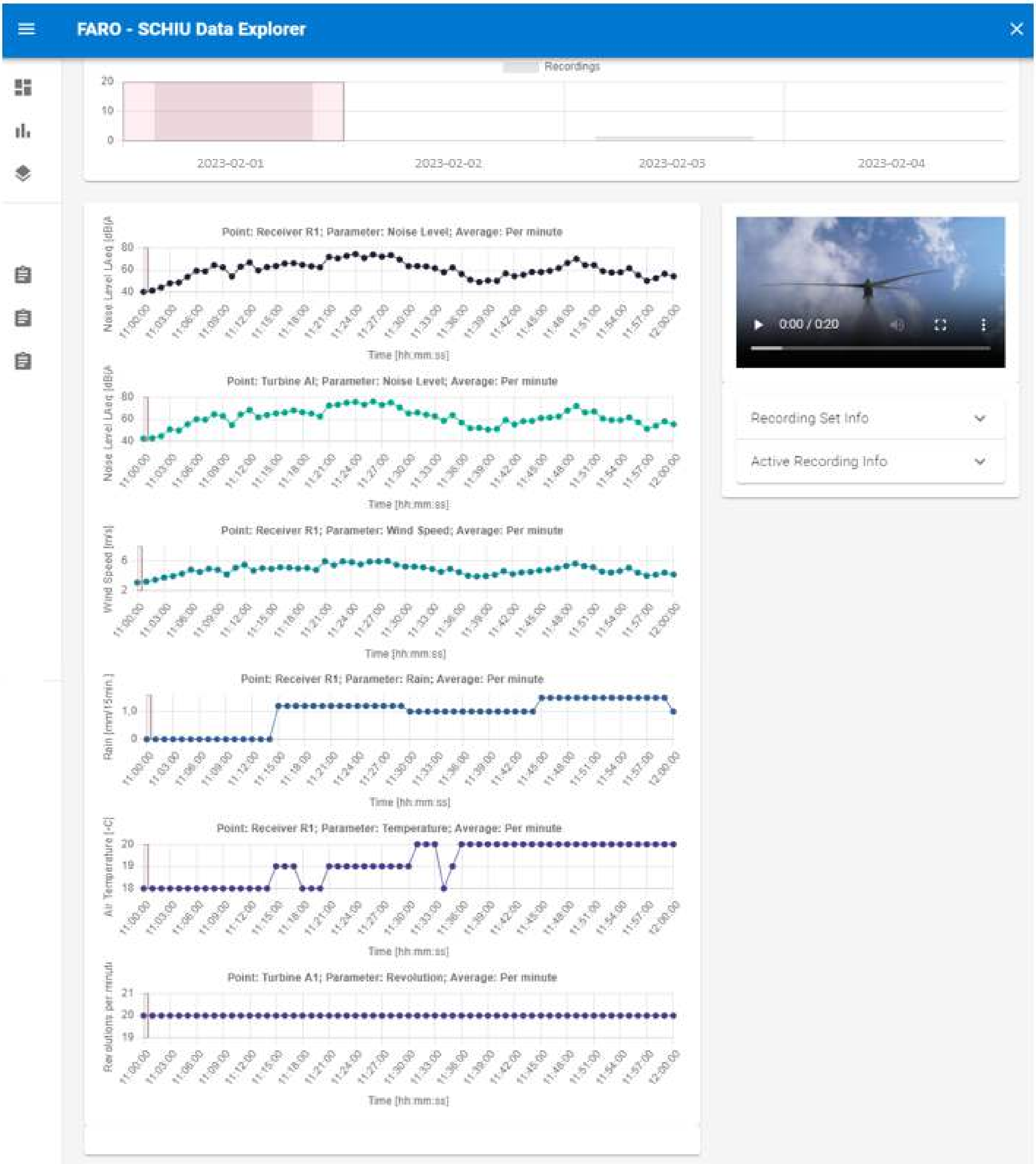


**Figure 1: General aspect of the main page of the continuous monitoring system platform developed**

## 2. **Audio/video recording**

In terms of audio/video recording, the developed continuous monitoring system has as main interests and specific features:

i. To have the best possible quality (in constant evolution) so that the audio/video that is possible to hear/see a posteriori, in the "office", is as close as possible to what a human being, with normal hearing/vision, would be able to perceive if he/she was hearing/seeing the sound/sources on site in real time.

ii. Maintenance of human privacy. An algorithm (in constant evolution) has been developed that allows, in terms of audio, to distinguish the type of noise source in presence, but, in the case of human conversation, it does not allow to distinguish what is being said. In visual terms a filter was used that allows you to see the shapes but does not allow you to identify the person, or other private information, such as vehicle number plates.

### 2.1 **Current quality**

The current quality of the audio and video of the developed monitoring system, as shown in the example available at the following link, and which already has the audio and visual "filters" applied, allows distinguishing the sources of noise that typically occur:

https://drive.google.com/file/d/1RRn3xuxasZVdHVGFAcZu3VsW5WFuITz-/view?usp=sharing

### 2.2 **Current audio privacy algorithm**

The developed audio privacy algorithm sought, essentially, to maintain the possibility of human detection of the type of noise source present, but not to allow determining what was being said, in the case of recording any human conversation.

An example speech is presented in the following links, in the original version and in the version in which SCHIU's audio privacy algorithm was applied.

- Original: https://drive.google.com/file/d/1Y9LdkFrloy2qODh-QxGTWdJ8TYr-jy_W/view?usp=sharing.
- With application of audio privacy algorithm: https://drive.google.com/file/d/1yuVgJ3IDZhFjpEPAaqoJXINBvNqbQWo9/view?usp=sharing.

## 3. **Other parameters**

The developed system registers, in addition to the raw data of the sound levels (see next subchapter "6.1Raw data"), the following parameters:

- Air temperature and humidity.
- Wind speed and wind direction.
- Rainfall.

The previous Figure 1 shows, e.g., the possibility of join analysis of noise levels, wind speed, rain and temperature at Receiver R1.

# 4. **Close to the noise source**

The system developed allows you to obtain, from a particular noise source of interest (or other location deemed relevant) in this particular case, from one or more wind turbines of interest, the same parameters / data that can be obtained from a Sensitive Receiver, i.e.:

- Raw sound level data.
- Audio/video recording.
- Air temperature and humidity.
- Wind speed and wind direction.
- Rain.

Close to the wind turbine is possible also obtain the rotation speed of the turbine (see the next subchapter “4.1 Wind turbine rotation speed calculation algorithm”)

The previous Figure 1 shows, e.g., the possibility of join analysis of:

- at Receiver R1: noise levels, wind speed, rain and temperature.
- at Turbine A1: noise levels, revolutions per minute

## 4.1 **Wind turbine rotation speed calculation algorithm**

Given the importance of the rotational speed of the wind turbines (see, for example, Luca 2012), an algorithm was developed which, based on the sound levels and video recorded with the wind turbines, allows counting the number of rotations per minute, as exemplified in the available video at the following link:

https://drive.google.com/file/d/16Dxux6YC1uKiyjVHrfWAetjvRL1kA8NU/view?usp=sharing

# 5. **Legal requirements (Portugal)**

In Portugal there are no specific requirements for Wind Turbine Noise, only requirements for the so-called Permanent Noisy Activities, contained in Article 13 of DL 9/2007 (Mainland Portugal and Autonomous Region of Madeira) and Article 25 of Regional Legislative Decree 23/2010/A (Autonomous Region of the Azores).

## 5.1 **Limit values, parameters used and reference periods**

In short, the requirements (limit values, parameters and reference periods) are as follows:

- Maximum Exposure Criterion:
    - Essentially dependent on the acoustic classification assigned by the municipality to the site:
        - Mixed Zone: $L_{den} \leq 65$ dB(A); $L_n \leq 55$ dB(A).
        - Sensitive Zone: $L_{den} \leq 55$ dB(A); $L_n \leq 45$ dB(A).

- Unclassified zones until classified or equated: $L_{den} \leq 63$ dB(A); $L_n \leq 53$ dB(A).

  - The parameters, with A weighting in frequency, must be representative of the annual energy average and of the following periods, in Portugal:

    - Mainland and Autonomous Region of Madeira:

      - $L_d$ (Day Level): 7h-20h; $L_e$ (Evening Level): 20h-23h; $L_n$ (Night Level): 23h-7h.

    - Autonomous Region of the Azores:
      - $L_d$ (Day Level): 7h-21h; $L_e$ (Evening Level): 21h-23h; $L_n$ (Night Level): 23h-7h.

    - The $L_{den}$ parameter is determined based on the following equations:

      - Continental and Autonomous Region of Madeira:

$$L_{den} = 10 \times log \frac{1}{24}\left[13 \times 10^{\frac{L_d}{10}} + 3 \times 10^{\frac{L_e+5}{10}} + 8 \times 10^{\frac{L_n+10}{10}}\right]$$

      - Autonomous Region of the Azores:

$$\mathrm{L_{den}} = 10 \times \log\left[\frac{14 \times 10^{\frac{L_d}{10}} + 2 \times 10^{\frac{L_e+5}{10}} + 8 \times 10^{\frac{L_n+10}{10}}}{24}\right]$$

- Discomfort Criterion.

  - Essentially corresponds to the difference between the Noise Rating Level, A weighted, $L_{Ar}$ , of the total noise (particular noise of the noise source in question plus background noise) and the Continuous Equivalent Sound Level, A weighted, $L_{Aeq}$ , of the background noise (total noise without noise from the noise source in question).

  - Parameters should be representative of the most critical month:

    - Day time (in Portugal: 7h-20h or 7h-21h): $L_{Ar} - L_{Aeq} \leq 5$ dB.

    - Evening time (in Portugal: 20h-23h or 21h-23h): $L_{Ar} - L_{Aeq} \leq 4$ dB.

    - Night time (in Portugal: 23h-7h): $L_{Ar} - L_{Aeq} \leq 3$ dB.

The developed continuous monitoring system thus allows, for each monitoring point:

- Define day, evening and night time.

- The constants that add to $L_e$ ($C_e$; typically 5 dB) and $L_n$ ($C_n$; typically 10 dB) in the $L_{den}$ determination equation.

- Obtain the average daily energy values of $L_d$, $L_e$, $L_n$ e $L_{den}$, depending on the previous definitions.

- Obtain the average monthly energy values of $L_d$, $L_e$, $L_n$ e $L_{den}$, according to the previous definitions and thus determine the most critical month.

- Obtain the average annual energy values of $L_d$, $L_e$, $L_n$ e $L_{den}$, according to the previous definitions.

- Possibility of determining times when, in a reasoned and justified manner, the particular noise of the noise source of interest is negligible, and the associated values may be considered characteristic of the background noise.

### 5.2 **Noise Rating Level**

The Noise Rating Level, $L_{Ar}$, in the Portuguese legislation (DL 9/2007) is given by:

$$L_{Ar} = L_{Aeq} + k_1 + k_2 \quad (1)$$

Where $k_1$ = 3 dB, if tonal characteristics are detected in the recorded noise, and $k_2$ = 3 dB, if impulsive characteristics are detected in the recorded noise.

#### 5.2.1 **Tonal characteristics**

The method included in Annex I of DL 9/2007, for detecting the tonal characteristics of noise within the evaluation time interval, consists of verifying, in the frequency domain and in third octave bands , whether the sound level of one band exceeds the adjacent ones by 5 dB(A) or more. In these cases, the noise shall be considered tonal.

#### 5.2.2 **Impulsive characteristics**

The method to detect impulsive noise characteristics within the evaluation time interval consists of determining the difference between the equivalent continuous sound level, $L_{Aeq}$, measured simultaneously with impulsive and fast time weighting filters. If this difference is greater than 6 dB(A), the noise shall be considered impulsive.

## 6. **Possibility of other requirements**

### 6.1 **Raw data**

To allow the greatest possible versatility, it was decided that the system would register raw information, duly calibrated, with a sampling frequency of 48 kHz.

This option thus allows to carry out further types of analysis at a later time, namely different frequency weightings or different time weightings.

### 6.2 **Current requirements**

For now, the system allows automatic verification of the following requirements:

- Portuguese legislation: DL 9/2007.
- Criteria for the assessment of low frequency noise disturbance from the University of Salford 2011 document.
- Criteria for $L_{den}$ < 45 dB(A), according to WHO 2018 document.

### 6.3 **Current frequency weightings**

For now, the system allows the use of the following frequency weightings:

- IEC 61672-1: 2013:
  - A, B and C weighting.
- ISO 7196:1995:
  - G weighting.

### 6.4 **Current tonal characteristics methods**

For now, the system allows the use of the following tonal characteristics detection methods:

- Portuguese legislation (Annex I of DL 9/2007).
- ISO/TS 20065:2022.

### 6.5 **Current impulsive characteristics methods**

For now, the system allows the use of the following impulsive feature detection methods:

- Portuguese legislation (Annex I of DL 9/2007).
- ISO/PAS 1996-3:2022.

### 6.6 **Current Amplitude Modulation**

Given the relevance of the Amplitude Modulation characteristics, for Wind Turbine Noise the system uses the method of the IOA 2016 document.

## 7. **Conclusions**

We have tried so far, and will continue to try in subsequent developments, that the continuous noise monitoring system, aimed at Wind Turbine Noise, is developed with the best-known state of the art, as explained in the previous chapters.

We also tried to make the system as versatile as possible so that, if necessary, justifiable and relevant, new types of analysis can be easily introduced.

It is therefore expected that the system can be effectively useful in controlling noise, perceived by Human Receivers (mainly at houses, but also schools and health facilities) that often exist in the vicinity of Wind Farms.

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