Application of the Harmonica Index for noise assessment in different spatial contexts

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Abstract. Currently, noise pollution deriving from traffic, industry and leisure activities is one of the main environmental problems that affect people quality of life and health. However, it is very difficult to quantify noise effects, because they depend on people noise level tolerance, environmental noise sources, methods of definition of noise exposure and indicators. The acoustic descriptors currently used, indeed, are hardly understandable for those who do not deal with the topic, thus limiting the comprehension of the damage caused by noise. Consequently, it is essential to provide information that is easier to understand and closer to the noise pollution perceived by people. Innovative acoustic indices, like the Harmonica Index, have been defined in recent years, to overcome the aforementioned limits. Their application to different spatial contexts, with the identification of the background and the event-based components of the environmental noise, can contribute to understand the influence of human activities on the quality of an acoustic environment. In this paper, starting from data acquired both in crowdsourcing and with traditional instruments, the application of the Harmonica Index to urban, peri-urban and rural areas in south Italy will show their acoustic characteristics that could be understood also by a non-technical public.

1. Introduction
In recent decades, the demographic expansion and the increase of human activities related to traffic, industry and leisure have strongly influenced the quality of life in cities. The road traffic, in particular, is one of the main sources of acoustic pollution in urban areas. Its negative impacts on the environment and human health depend also on people noise level tolerance and systems of definition of noise exposure. In order to anticipate and adopt methods of mitigation and modelling of noise, it is necessary to study and deepen the noise impact on urban environments, because these will represent the sound environments of the future [1]. Specifically, the mitigation actions are the basis of an effective environmental policy which promote an overall environmental awareness and the use of the best practice of developed countries [2].

Generally, noise regulations are aimed at avoiding significant nuisances, disturbances and health effects. In 2002, the European Noise Directive (END) defined that all member states had to produce, every five years, noise maps and noise management action plans for urban agglomerations and major roads, railways and airports [3]. These maps and plans can be considered instruments for the management and reduction of environmental noise to protect human health and preserve the natural soundscapes [4-6].
In spite of the actions defined by local authorities with the purpose of applying the END that led to improvements in the effectiveness of policies for the management and reduction of environmental noise, it is necessary, also, to define appropriate noise indicators that can be understood by the public and can contribute to increase a general awareness in the noise pollution. The standard noise indicators, generally expressed in decibel, are hardly understandable by people, which are not able to comprehend the damage caused by noise in its entirety [7, 8]. Therefore, it is essential to define innovative indicators able to provide information that can be easier to understand and closer to the noise pollution perceived by people. As a consequence, a bottom-up approach could emerge that would lead to the definition of further strategies that could integrate the existing official ones [9, 10].

In this paper, after a preliminary brief recognition on the main noise indicators used currently, an innovative index, the Harmonica Index, will be presented and applied to different spatial contexts, using both crowdsourcing data and data acquired with sound level meters, in order to feature the different acoustic environments in different time periods.

2. Materials and methods

2.1. Main noise indicators

The noise indicators have a fundamental role for noise management because they can be considered tools for supporting authorities on the adoption of the suitable noise abatement measures.

Traditional noise indicators are defined according to different calculations for the evaluation of the environmental sound level, in relation to the input data, the weather conditions and the period over which they are calculated [11-13]. Most of the EU member states use the same noise descriptors for road, rail and industrial noise, i.e. the A-weighted long-term average sound level determined over all the day, evening and night periods of a year (L_{den}) and the night-time noise indicator (L_{night}) determined over all the night periods of a year.

Since the main aspects for the analysis of the environmental noise are energy, time and spectrum, other classifications of the noise indicators can be find in the literature. In particular, in [7, 14] the noise indicators are divided into energetic, statistical, noise variations, spectrum and emergences descriptors. The energetic descriptors, such as the equivalent continuous level L_{Aeq,T} referred to a T time interval, give information about the total sound level and are, generally, used by legislations, which establish their limit values. The statistical (e.g., the percentile levels, L_{An}) and the noise variation (e.g., the standard deviation, \(\sigma_{L}\)) indicators of the sound levels detected in the T time interval, describe the variability of the levels (e.g., L_{A10}-L_{A90}). Moreover, a statistical indicator can represent a level of the distribution of higher energy sound events (e.g., L_{A1}) or background noise (e.g., L_{A95}). The indicators representative of the spectrum of the sound environment are, for example, the sound ecology indicators, for discriminating presence of biophonic sounds and anthropogenic sounds, the Spectral Gravity Center (SGC) of the 1/3 octave band spectrum, that is very sensitive to events, the percentile levels for frequency bands and the difference L_{Ceq}-L_{Aeq} which describes the amount of low frequencies. Furthermore, Asensio et al. [15] outlined a set of descriptors for emergences which better enables the application of more novel approaches to the evaluation of the effect of the new soundscape due to the measures against COVID-19 on people’s subjective perception. They are based on the number of noise events and the percentage of the time, that exceed a given threshold.

In spite of the large number, no indicator can describe the complexity of sounds in different territorial contexts in its entirety. For example, the L_{Aeq,T} when calculated on short periods, is highly influenced by noise peaks. Moreover, each statistical descriptor only corresponds to one point of the L_{Aeq,1s} distribution and, therefore, one descriptor value can also correspond to very different sound environments [7]. Consequently, the various indicators offer different points of view of the sound levels variations and can be considered complementary to each other.

Moreover, the standard acoustic indicators are generally expressed in decibel unit, which has a logarithmic nature and is complicated to explain to people and to associate to their perception of noise [16]. As a consequence, innovative acoustic indices must be defined considering further criteria.
2.2. Innovative indices: the Harmonica project

In order to improve the noise phenomenon comprehension with the use of an appropriate descriptor, it is necessary to build an innovative index with reference to a suitable method of calculation and representation [17], which must consider the spatial and temporal specificities and highlight the background noises and noise peaks. Furthermore, the innovative index must be based on a participatory process, focusing also on the sound perception that people have of an environment. Based on these criteria, a new index, integrated with the traditional descriptors that are mandatory by legislation, could provide additional information and evaluate the quality of the acoustic environment [18].

Ribeiro et al. [17] described the development of four indices (P1, P2, CY, and CC), based on different approaches, which integrated both the continuous and the sporadic nature of noise. These were the precursors of an innovative Common Noise Index, based on a nuisance scale characterized by a score from 0 to 10, that were developed in the framework of the Harmonica project, supported by the European Commission (LIFE program). The HARMONised Noise Information for Citizens and Authorities (HARMONICA) project had the main goal of creating a normalized noise index for the general public and the authorities to improve the efficiency of the EU policies on environmental noise management.

The construction of the innovative index, finally named Harmonica Index (HI), was organized in 3 phases, as shown in figure 1 [18]. First, the selection of the index parameters resulted from the principal components analysis (PCA) on 60 hourly acoustic descriptors, calculated using $L_{Aeq,1s}$ as the elementary data. All the data were acquired with a measurement campaign organized in 24 sites representative of the eight main types of noise exposure (for instance land transport noise, air traffic noise, and quiet areas) in different spatial contexts (urban, suburban, and rural). Secondly, in order to evaluate the comprehensibility and acceptability of the index, the opinion and perceptions of the public were considered by conducting both face to face and laboratorial interviews, involving different stakeholders, like residents, general public, associations and local authorities. Finally, the HI formula was developed (Figure 1), considering two components: the background noise, BGN, and the EVT, which considers the peaks linked to specific noise events.

The HI is easy to calculate since it uses measurement data usually collected by noise measurement devices. Its complete structure represents, indeed, a combination of the equivalent level, $L_{Aeq}$ and the $L_{A95_{eq}}$ which is the level that is exceeded 95 percent of the measurement time. Specifically, $L_{A95_{eq}}$ is the value in [dBA] integrated over 60 minutes of the series of 3600 values of $L_{A95}$ calculated from the single $L_{Aeq,1s}$ contained in a 10-minute time interval, shifted progressively every second [7, 19, 20].

1. Selection of the index parameters
   - Choice of 24 sites representative of 8 types of noise exposure in different environments
   - Measurement campaigns of $L_{Aeq,1s}$
   - Calculation, on an hourly basis, of 60 different energy- and event-based descriptors
   - Elimination of redundant descriptors
   - Definition of uncorrelated descriptors

2. Integration with people opinion and perceptions
   - Face to face interviews to 246 residents of the 8 areas
   - Laboratorial interviews following binaural playback to 130 people, divided into 3 groups: general public, associations, and local authorities

3. Development of the Harmonica Index (HI) formula
   - background noise subindex - $BGN = 0.2(L_{Aeq,1s} - 30)$
   - peak noise subindex - $EVT = 0.25(L_{Aeq} - L_{A95_{eq}})$

   HI = $BGN + EVT = 0.2(L_{A95_{eq}} - 30) + 0.25(L_{Aeq} - L_{A95_{eq}})$

Figure 1. Methodology of construction of the Harmonica Index [16]
With the aim to understand the nature of sound, the HI is represented graphically [21] by only two basic geometric shapes, i.e. the rectangle for background noise and the triangle for the peaks of events (figure 2(a)). This representation is very effective and allows people to distinguish the two components in different spatial contexts. For example, during daytime, in an industrial area, a high value of the BGN sub-index could generally denote the presence of working technological facilities, while, in an urban centre, the increase of background noise could be mainly generated by vehicular traffic. However, the representation of the EVT could highlight specific situations which differ from the standard conditions of a place. Furthermore, the two shapes can be painted with a green, orange or red colour consistent with the value of the index. This allows the evaluation of the quality of the acoustic environment according to the critical values recognized by the World Health Organization (WHO), which varies depending on day and night time periods (figure 2(b)), because of a higher sensitivity to noise during the night.

In order to evaluate the relationship between the Harmonica Indices (BNG, EVT and HI) and the END noise indicators (Ldn, Lec, Ln and Lden), Prascevic et al. [22] carried out a correlation analysis for their different combinations. They obtained high values of the Pearson correlation coefficient, thus highlighting the high strength of the association of noise indicators and Harmonica indices and the adequacy of Harmonica index for the environmental noise assessment.

![EVT and BGN](image1)

2.3. Methodology

Since the aim of this study is to define the characteristics of an acoustic environment in different time periods, the HI can be applied to different spatial contexts, considering data acquired with both traditional instruments, like the sound level meters, and innovative techniques related to the crowdsourcing [1]. These applications can contribute to get information about the noise sources features of a specific spatial context, to increase people awareness in noise pollution and to define more appropriate actions by local governments.

3. Applications of the Harmonica Index to different spatial contexts

In this section, three applications of the HI in different spatial contexts are presented. The case studies (figure 3) are located in the municipalities of Palomonte, Capaccio Paestum and Nocera Inferiore in the Province of Salerno (South Italy). The three sites of investigation were defined with the aim to analyse both rural and urban contexts. Specifically, as shown in figure 4, with regards to the rural area of Palomonte, the point of measurement is about 100 m far from a local road; Capaccio Paestum point of measurement is located in one of the city centers of the municipality close to a provincial road (SP277) and the point of measurement of Nocera Inferiore is located in an agricultural residential mixed area.

The measurement campaign was organized in five days, from the end of November to the beginning of December 2020, as reported by table 1. Even though the measurements were influenced by the restrictions due to the COVID 19 pandemic and, generally, the environments are less noisy, the aim of the study was, also, to determine the habits of the residents with the calculation of the HI. Since the HI is calculated on hourly base, each campaign was organized to acquire each data per single hour. The data acquisition was based on both a traditional sound level meter, namely Fusion produced by 01dB (class 1), for the case study of Nocera Inferiore, and an innovative technique, that involve people to collect data with their mobile devices for the other two case study. The traditional measurement...
technique is generally more accurate than the second; anyway, the positive outputs of crowdsourced data have been already discussed in [1, 23-28].

Figure 3. Territorial framework.

Table 1. Measurement campaign details

| Site               | Dates               | Time period          | Data acquisition |
|--------------------|---------------------|----------------------|------------------|
| Palomonte          | 27 November 2020    | from 2 pm to 3 pm    | crowdsourcing    |
|                    | 29 November 2020    | from 2 pm to 3 pm    |                  |
| Capaccio Paestum   | 01 December 2020    | from 6 am to 24 pm   | crowdsourcing    |
|                    | 02 December 2020    | from 0 am to 5 am    |                  |
| Nocera Inferiore   | 28 November 2020    | from 3.50 pm to 6.50 pm | sound level meter |

In this study, the crowdsourcing data were acquired with the NoiseCapture application, that is a component of the Noise-Planet project [25]. This project aims to provide an integrated platform of tools, based on scientific research, dedicated to the acquisition, modelling and evaluation of environmental noise measurements. It is led by two French research teams: the Environmental Acoustics Laboratory (Eiffel University, former IFSTTAR) for environmental noise research and the DECIDE Team (Lab-STICC - CNRS UMR) for GIScience. In this project, the data is collected from the free and open-source Android NoiseCapture application and shared from the OnoM@p Spatial Data Infrastructure (SDI) [26, 27]. The Noise-Planet project is integrated also with a free GIS-based model to compute noise maps and an interactive maps viewer, to display noise data collected by the community. The NoiseCapture app allows computing each second the equivalent A-weighted sound levels and then sharing data with the community [28]. From the NoisePlanet platform, it is possible to download all the acquired data and to export them to the QGIS environment and determine the $L_{Aeq}$ and $L_{A95}$, needed to calculate the HI.

3.1. Results and discussion
The application performed in the rural area of Palomonte, based on crowdsourcing data collection, had the main objective to highlight the differences of the acoustic environment in two days, a weekday and a public holiday, and to evaluate the influence of human activities on the sound levels of the study area. The data were collected using an Android smartphone and the NoiseCapture application.

Figure 4 shows the numerical values of the traditional indicators, $L_{Aeq}$ and $L_{A95}$ and their graphical trend over the observational period, i.e. 1 hour, with a time basis of 1 second, the numerical value of other percentile levels (10, 90 and 50) and the minimum and maximum value ($L_{min}$ and $L_{max}$), and the numerical Harmonica index, with its graphic representation. In particular, results refer to measurements made starting from 2 to 3 pm on Friday 27th (figure 4 (a)) and on Sunday 29th (figure 4 (b)). The two graphs show that there is a higher level of both background noise and noise peaks on
Friday. The noises detected are mainly due to the presence of pets and chicken coops in the vicinity: the noise peaks, indeed, differ little in the two days. The difference in the peak is due to the transit of heavy vehicles and to a greater number of vehicular traffic due to a series of work activities in the workday. Furthermore, the decrease of background noise on Sunday is due to a reduction in circulating vehicles and almost no mobility in the surroundings.

Figure 4. Rural area of Palomonte: noise indicators and HI at 2 pm on (a) Friday 27/11/2020 and (b) Sunday 29/11/2020.

In the municipality of Capaccio Paestum, 24-hour measurements were carried out, so that the representation of the HI can be extended to the entire day with the aim to have a general trend of the noise changes in the different hours of the day. Also in this case study, the data were acquired with the use of an Android smartphone. The measurements were grouped into a single 24-hour chart in which it is possible to observe how the index varies during the day and night time periods, from 6a.m. to 9p.m. and from 10p.m. to 5a.m., respectively (figure 5). Two colors, green and orange, were used according to the acoustic environment classification, reflecting the quality objectives of the WHO and the values recognized as critical for noise. In the early morning hours, a very quiet environment can be observed, with relatively low background noise and events; instead, from 11 am to 12 am a slight increase in noise is perceived, due to the increase of vehicular traffic. Then, there are no significant variations in values until the evening, where a slight increase is perceived mainly due to anthropogenic activities. During the night there is a clear increase in the sub-index EVT compared with the component BGN. This is mainly due to a reduction of the background noise in the night period and, therefore, the noise peaks due to single events will be more evident. In particular, Figure 6 (a) shows that at 1 am the BGN value is practically zero, as 30 dBA is the minimum threshold beyond which the noise can begin to be perceived as annoying in the external environment. In the time range from 1 to 2 am, as the L_{A95eq} index is less than 30 dBA, the value of the BGN sub-index is assumed to be zero. Then, in the time range from 2 to 3 am, there is a sudden increase in both background noise and peaks due to strong gusts of wind and a rainy event that began at 2:30 am and ended at 3 am, visible in the time history in
Therefore, the HI calculated at 3 and 4 am reproduces an environment with a good acoustic quality.

![Figure 5. HI over 24 hours for the urban area of Capaccio Paestum](image)

In third case study, corresponding to a mixed area (rural and residential) in Nocera Inferiore, the HI was evaluated starting from data acquired with a class 1 Fusion sound level meter. The results obtained did not highlight any particularly significant events and were coherent with the surrounding environment. Figure 7 shows the obtained results related to two different hours of measurement in the afternoon of the same day. It is possible to observe the same EVT at 3:50 and 5:50 pm, while an increase of the BGN at 5:50 pm indicates an increase of road traffic. If considering the period in which the measurements were made, this context is characterized by an overall good acoustic quality.

![Figure 6. Capaccio Paestum: HI at 1 am (a) and 2 am (b) on Wednesday 02/12/2020](image)
4. Conclusions

In this paper, the Harmonica Index, developed in the framework of the Harmonica Life project, was applied to three territorial contexts, i.e. an urban, a peri-urban and a rural area, starting from data acquired both with tools that allow the acquisition of data in crowdsourcing, through applications for mobile devices, such as the NoiseCapture application, and with traditional instruments, like a class 1 sound level meter.

In the two applications based on crowdsourced data acquisition, it was possible to highlight the variation of the two components of the index in the different spatial and temporal contexts. It was also observed that, due to its structure, the HI is very sensible to noisy events over low background noise conditions. This was confirmed during night period measurements in one of the case studies, when a sudden wind and rain storm led to a strong increase of the index. This aspect of the index must certainly be studied in depth. In the third application, a class 1 Fusion sound level meter was used for correctly defining the acoustic quality of the environment, underlining, once again, the versatility of the index and the simplicity of its comprehension. Since the values of the HI were influenced by the COVID 19 restrictions, it would be interesting a comparison with the potential results under ordinary conditions in the same locations.

Further future developments could involve the integration of the study carried out with soundscape measurements and the evaluation of psychoacoustic parameters with questionnaires administered to
the visitors of the area during the measurement campaigns, in order to find the human perception and the sense of pleasantness of the area. This type of method would complete the study, giving a deepening and a broader and more precise vision of the perception of people with respect to the variation of the acoustic environment.

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