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OPENOISE: A FREE AND OPEN SOURCE PROJECT FOR ENVIRONMENTAL NOISE ASSESSMENT

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ABSTRACT

OpeNoise is a multi-platform, public and open source noise assessment project, implemented by the Environmental Protection Agency for the Piedmont Region (Arpa Piemonte – Italy), with the support of the Municipality of Turin and the Metropolitan City of Turin.
The goal is to provide a first-level and free access tool for public administrations, consultants, universities and companies in the field of environmental acoustics.
The OpeNoise project is divided in three branches: an application for noise measurements through mobile devices (OpeNoise Meter), a script for noise mapping (OpeNoise Map), available within the free and open source geographical system QGIS, and a tool for acoustic data analysis developed in the R-Project framework for statistical computing (OpeNoise Analysis).
This paper describes the major technical features of these tools, their possible practical uses, as well as some application examples and planned future developments.

Keywords: *smartphone, modelling, analysis, open-source, GIS.*

1. INTRODUCTION

The protection from noise pollution is included in the 2030 Agenda for Sustainable Development adopted by United Nations [1]. In fact, noise affects a large number of citizens and is perceived by the public as one of the biggest environmental problems; it can involve people both physiologically and psychologically, interfering with basic activities such as sleep, rest, study and communication.
The World Health Organization (WHO) has classified environmental noise as the second worst environmental stress factor in Europe, behind only air pollution caused by fine particulates [2].
In order to reduce these harmful effects and in general the exposure of Europe's population, the European Parliament and Council adopted the Directive 2002/49/EC relating to the assessment and management of environmental noise, also known as the "END" [3].
The measurement and modeling of noise levels inside and outside urban agglomerations is a key issue in order to provide the information needed.
To achieve a sufficiently wide spread of measurement points, low-cost monitoring systems may be an appropriate solution, provided that sufficient data accuracy is guaranteed.
The use of smartphones equipped with appropriate phonometric applications can be a solution that meets this need.
Mobile applications such as NoiseTube [4], SoundPrint [5] and Noise Capture [6] are some examples where smartphones can be used to measure and report noise levels.
Similarly, the OpeNoise project aims to build a free and open-source tool for measuring noise, plus providing a tool for analyzing measured data and mapping noise over large areas.

2. OPENOISE METER

OpeNoise Meter is the part of the project dedicated to measuring noise through mobile devices: it consists of an app that can be downloaded from the official Android and iOS stores and can emulate the operation of a sound level meter.
The project has been under development since 2016 and the latest version, 2.0.2, was released in July 2018. While we are

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writing this paper, a new major version is under development and will be published within a few months. In this new version, OpeNoise Meter will be compatible with the latest versions of operating systems and smartphone models currently on the market and will be enriched with new features and a more modern layout. Currently, more than 8000 Android and 6000 iOS devices have OpeNoise installed.

2.1 Specifications

OpeNoise Meter allows to measure the equivalent A-weighted sound pressure level, evaluate minimum and maximum values, analyze frequency components through third-octave and linear (FFT) filters, plot frequency vs time data (spectrograms) and store data in log files.
The interface has a textual part, where the minimum and maximum value, the A-weighted sound pressure level every 1 second ($L_{Aeq,1s}$) and the running LAeq can be easily displayed. All values can be reset with a special "Reset" button.
Like a normal sound level meter, the interface presents four possible graphs: the data time history, a bar with the minimum, maximum and average level, the unweighted spectrum in third-octave bands, the FFT spectrum (A-weighted and unweighted) and the spectrogram.
Sound level measurement can be done through the device's internal microphone or using an external sensor, inserted through the appropriate input.
A gain can be set in order to calibrate the device. This operation, to be performed by measuring a known sound pressure level, can be a critical point, as it is currently not possible to define a standard and repeatable procedure (considering the number and the variety of devices and microphones that can be used).
Measurements without a proper gain setting can be affected by significant errors.
To perform the frequency analysis, an FFT (Fast Fourier Transform) is calculated with the following settings:

- sampling at 44100 Hertz;
- Hanning window, to limit the aliasing effect;
- frequency resolution: 5.4 Hertz.

The code is available on the GitHub platform [7] and released with an opensource license.

2.2 Tests

The reliability and accuracy of the measurements made with OpeNoise have been tested several times in these years, suggesting that it can be used to provide, under certain conditions, informative (but not legally binding) environmental noise data.
In addition to previously published tests [8], two different instrumental laboratory tests are reported in this paper: a comparison of dynamic range and of gain value for 18 different smartphone models (Figures 1 e 2).
The tests were performed using a box set up to simulate an anechoic chamber and were conducted generating different types of acoustic signals inside the box and comparing the sound level read by the smartphone equipped with OpeNoise and a Class-1 sound level meter. All tests were performed using the device's internal microphone. The source was white noise and the measurement lasted until the levels stabilized.
Most of the tested smartphones, selected from the personal available devices, has a good dynamic range between 30-40 and 100-110 dB(A), a better result than in the previous study [8]. Gain, on the other hand, has a wide range in Android smartphones while it is substantially constant for iOS devices (+ 24.0 dB).
This can be explained by the many different brands and models introduced in the market for Android compared to iOS.

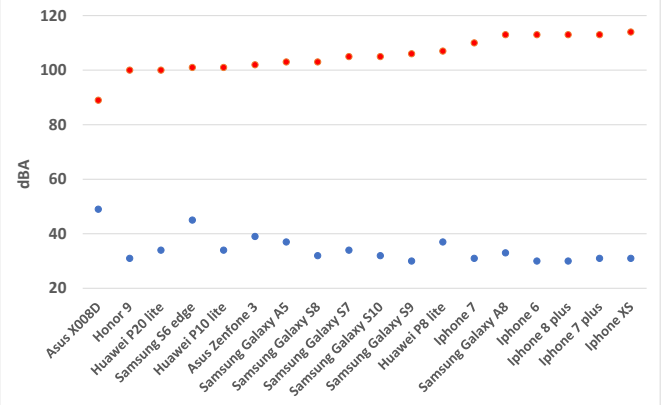

Figure 1. Dynamic range comparison (low level measured: blue dots, high level: red dots)

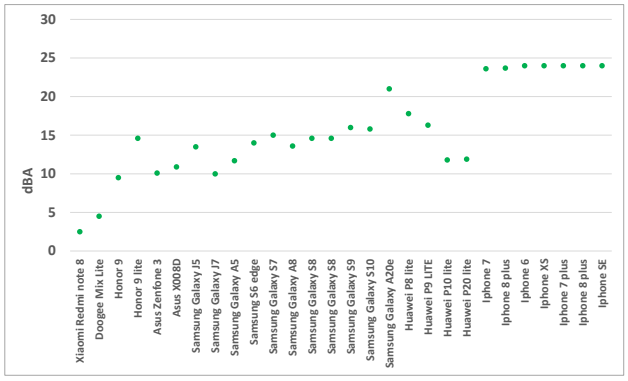

Figure 2. Gain values comparison

2.3 Applications

There are many possible applications by having a small sound level meter in one's smartphone.
In recent years, we have been contacted by high schools, colleges, acoustics technicians or private citizens who wish to use OpeNoise Meter for various reasons [9, 10].
Citizen-science initiatives can also be successfully implemented using the app.
In our experience, we are using OpeNoise Meter to create a real-time and low-cost noise monitoring network [8].

3. OPENOISE MAP

OpeNoise Map, developed in collaboration with Onegis, aims to create a free and open-source platform for noise modelling [11, 12], similar to the NoiseModelling initiative [13].
The project has been under development since 2014 and the latest version, 2.0, was released in July 2022. The plugin is a QGIS [14] plugin, written in Python v.3 PyQt6, and is provided under the GNU GPL v.2 license with English language support. The new version includes updates to comply with recent amendments to the European Directives and integrates new features. As of April 2023, the plugin has been downloaded over 34000 times since its release, while version 2.0 has been downloaded 2300 times.

3.1 OpeNoise Map 2.0

Since its inception, the OpeNoise Map plugin has been designed to map road infrastructures and calculate noise levels according to the END - European Noise Directive 2002/49/EC [15]. The plugin supports shapefile that contain basic information necessary for acoustic modeling, such as building heights, traffic flows and speed, etc. The plugin returns results as GIS layer (both geometrics and table data), facilitating data analysis and interpretation. However, it can also be used for macro-simulations beyond road infrastructure mapping. The new features of the OpeNoise Map plugin, version 2.0, include:

- CNOSSOS-EU roads emission according to [16-17]
- Added storage of road emission levels in the source layer
- Custom receiver point height
- Custom building height
- Added horizontal pure diffraction, no ground effect in homogeneous condition, and vertical pure diffraction according to [16-17]
- Added the ability to skip diffractions computation
- Added the ability to create receiver points according to § 2.8 [17]
- Added new module: draw contour lines and exposed area to noise according to § 2.8 [17]
- Added new module: noise exposure for people and dwellings according to § 2.8 [17]
- Added new module: assessment of harmful effects of environmental noise for $N_{NA,road}$ and $N_{HSD,road}$ according to [18]

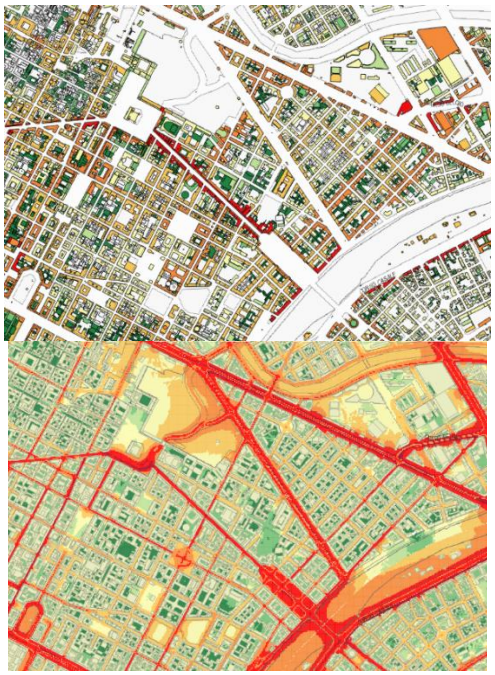

Figure 3. Excerpt of the noise map of the City of Turin calculated with OpeNoise (top: level assigned to buildings - bottom: equispatial grid)

3.2 Advantage and limitation

The OpeNoise Map 2.0 plugin fully complies with road emissions based on the CNOSSOS-EU calculation model, except for the simulation of crossing with traffic lights or a roundabout, the implementation of which remains complex. Previous versions implemented geometric divergence, pure diffraction for horizontal obstacles and air absorption in accordance with [19]. The ability to consider 3D propagation obstacles and implement pure diffraction for vertical obstacles is a significant advantage of the new version of OpeNoise Map. This means that the plugin can consider more complex and realistic environments when modeling noise propagation, which can lead to more accurate results. In addition, the ability to create receiver points at different heights (the default is 4 m) and to create isolevel curves at different heights using the new *Contours Level* module allows for more detailed analysis of sound levels at different floors of buildings or in other elevated areas. The new *Noise Exposure* module provides a simple tool to estimate the population and dwellings exposed to noise and potential health effects [17-18]. Since the distribution layer of dwellings within a building is hardly available to the user, a simplification was made by considering the population and dwellings within a building arranged uniformly.

Large simplifications remain in the acoustic modeling: the effect of terrain, atmospheric conditions, and reflections from obstacles have not been implemented and the terrain is considered flat. Therefore, validation of the plugin according to ISO/TR17534 [20] is still far off.

The OpeNoise plugin has the advantage of being contained in an open source GIS tool (QGIS), which provides extensive map data management and manipulation capabilities. However, non-programmable updates to QGIS may cause problems with OpeNoise Map, which would require specific porting. Consequently, user feedback and bug reports are essential for maintenance and improvement of the plugin, as in any open source project.

4. OPENOISE ANALYSIS

Environmental noise monitoring produces a lot of data that need post-processing for technical evaluations.

There are a variety of commercial software that perform this task but it is rare to find open source ones.

The OpeNoise R package is a library that allows the analysis of acoustic data acquired by sound level meters through the use of the R programming language [21].

The OpeNoise R package includes several algorithms and simple functions and thus represents a versatile toolbox that can potentially be improved with the help of the user community.

4.1 Main functions

The main functions of the library are:

- *LdenCalculator(…)* - to calculate both daily and day-evening-night noise level. Currently, the function calculates the index according to the Italian division of the day-evening-night period (day: 06-20, evening: 20-22, night: 22-06);
- *search.tone(…)* – to search within a measurement for the presence of a tonal component as defined by Italian regulations. The isophonics are based on the A curve (ISO226:1987) [22].
- *SearchImpulse(…)* - this function searches impulsive event within a measurement acquired at 100 ms as defined by Italian regulations [23];
- *IntrusiveIndex(…)* - to calculate the intrusiveness index according to the Italian technical specification UNI/TS11844:2022 [24].

4.2 Other functions

The library has also specific functions commonly used such as calculation of percentiles, time weighted and unweighted energy average, calculation of SEL (Single Event Level), calculation of energy sum or difference, plot of measurement time history (Figure 6), plot of time history with selected frequency components overlapped (Figure 7), plot of spectrum and plot of selected percentile versus frequency, etc.

4.3 Shiny app

To facilitate the use of the OpeNoise library, we have been developing a dedicated Shiny dashboard (Figure 8).

This makes the functions more immediate to use but at the same time decreases the flexibility of the application.

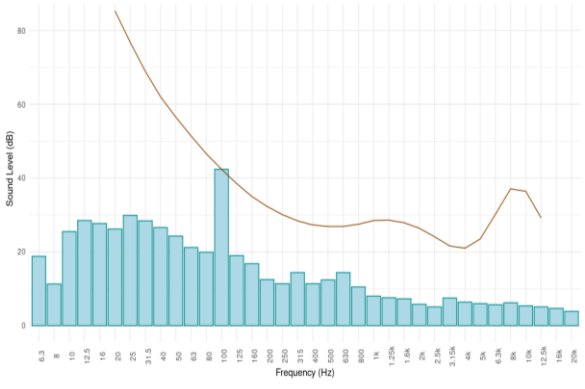

Figure 4. Example of 1/3 octave linear minimum level spectrum with the lowest isophone curve touching at least one band.

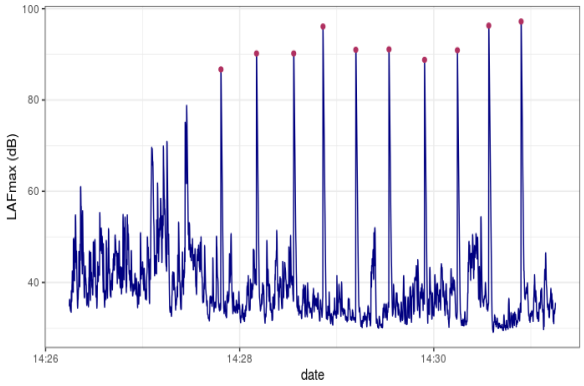

Figure 5. Example of time history (blue line) with impulsive events identified (red dots).

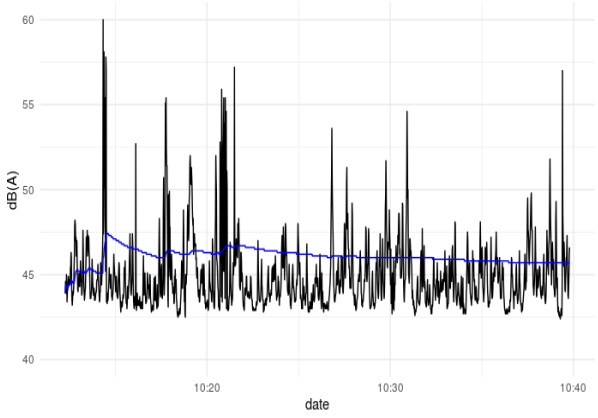

Figure 6. Example of L_{Aeq} time history (black line) and running L_{Aeq} (blue line).

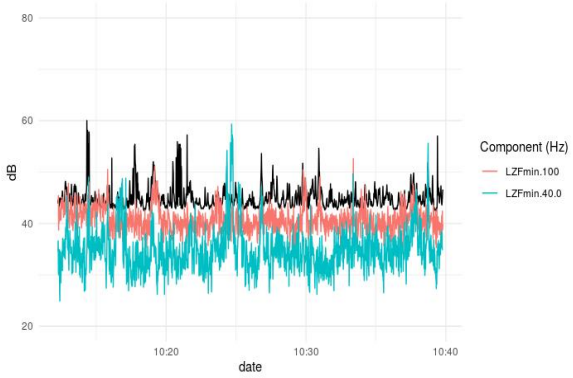

Figure 7. Example of overall L_{Aeq} time history (black line) with two frequency components (100Hz: red line, 40Hz: cyan line).

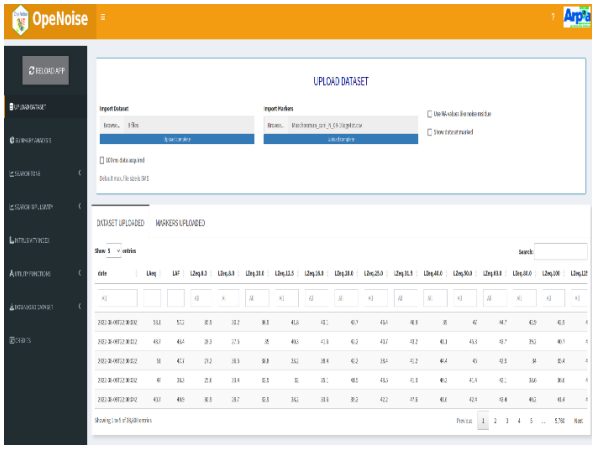

Figure 8. Screenshot of Shiny OpeNoise dashboard.

5. FUTURE DEVELOPEMENTS

A new major version of OpeNoise Meter is under development and will be released in a few months.
This version will ensure a full compatibility with the last Android and iOS operating systems, bringing several improvements and new features, as well as a new modern layout.
Among the new features, the work focused on:

- creating a gain values database with the aim of helping the users to set this parameter;
- increasing the acoustic characteristics of the app, such as adding pure tone identification or Z- or C-weighted levels;
- creating a database of user measurements, also collecting information on soundscape quality.

OpeNoise Map version is also currently under development, with the aim of reducing calculation time and of introducing additional features such as the assessments of ischemic heart disease ($N_{IHD,road}$) consistent with the regulation [24].
In addition, a validation of the calculation model will be carried out by comparison with commercial software, considering the limitations described above.
It is hoped that the European regulations will be revised to provide for the possibility of using simplified calculation models for the assessment of environmental noise, especially in high-density residential area, so as to limit the costs for public administrations. In this way, financial resources would be focused on the execution of Action Plans, which represent the final and concrete goal of noise reduction according to the Directive 2002/49/EC.

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