Urban Sounds:
Developing better dimensional interpretation models

A new approach on noise pollution and environmental assessment

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Impact Statement

Urban quality of life is a societal demand that is growing stronger in Europe.

More people is basing its lifestyle and residence options based on the quality of life of the urban environments available.

Noise pollution is a great concern in Europe, where cities are old and planned centuries ago.

The creation of parks and urban gardens is being promoted by municipalities to “sponge" the urban landscape and minimize the reflection of noise in building crowded areas.

This white paper describes a new vectorial model to evaluate the urban sounds based on its character and aggressiveness.

Possible applications are:

- Lifestyle options within the urban reality
- Real State: Renting or buying in peaceful areas
- Tourism: Enjoying City places while relaxing , avoiding crowds and noisy areas.
- Outdoor activities planning (Bicycle, walking)

The authors are here proposing the creation and future use of an Urban sounds Index, where the complex sound environment of a certain urban area can be evaluated following an easy to use vectorial model

Abstract

The perception of living quality in the cities has changed over the last 20 years in Europe.

The increased adoption of pedestrian zones in downtown areas where the traffic to motor vehicles is restricted, the incorporation of hybrid and electric vehicles that are much less noisy than the old combustion engines, also the completion of the urban infrastructure to incorporate technological changes (fiber optic networks, Mobile network repeaters) make the use of public works machinery much less necessary than before.

On the other hand, citizens are asking quieter and peaceful urban landscapes. More parks and less traffic. Less urban aggressiveness.

Large European cities have Sound Pressure Level (SPL) monitoring stations that report the ambiance dBA level, and create average accumulative (Leq) levels of the sound, that the citizens are exposed to.

However, The authors have found that a one minute average Leq (1min) of 65 dBA can be generated from a pneumatic hammer or from the sound tree branches with some traffic background noise. That fact illustrates how bad is ubiquitous Leq providing an abstraction of urban sounds.

This white paper describes new models to measure, characterize, interpret and represent urban sounds using audio, color and image using the FFT transform.

We make a proposal to use Artificial Intelligence tools to classify the sound at the sensor edge.

Finally this paper describes innovative models to evaluate urban sounds far beyond the measure of the Sound Pressure Level at the data platform side.

Background

"Urban sounds" is not a new concept although since 2016 the term has been accepted and increasingly used to define the research, and the effects on society of the urban landscape into the citizens.

Fuller 1966 which first coined the term "Urban Sounds". Key texts published in the early days of the World Soundscape Project, such as Davis, et al. 1977, deal with village soundscapes rather than city soundscapes, where traditional sounds were thought to need the most urgent documentation and protection.

Truax 1978 sets out an agenda for such “acoustic ecology.” Schafer and Truax’s approach has nevertheless influenced urban acoustics and planning research, where the call to plan better acoustic environments, known as soundscapes, has been taken up .

Brown, et al. 2016 discuss this kind of soundscape research. Bull 2016 and others established a separate cultural studies tradition of researching urban sounds.

Such work is introduced in the overview Gandy 2014. Here, the term soundscape is sometimes embraced and adapted, as Kelman 2010 explains.

Not everybody is following the same research line. Others have rejected it.

Ingold 2007 is a notable critique of the soundscape concept. Ingold argues that thinking of sensory experiences like hearing in terms of landscapes is unhelpful since sound is more dynamic than physical geography and our encounter with it more time-bound and embodied.

In the Appendix 6 a reference is provided to the previous research relevant to this white paper.

1,- Sounds and Noise. Theoretical research and the engineering perspectives

The mentioned research reference perspective addresses the problem from a theoretical and researcher's point of view.

The authors believe that for a certain research to be valid for societal development, It has to address problems and propose solutions.

How sounds are evaluated today

Sound pollution can be defined as any unwanted or disturbing sound that affects the health and well-being of the living beens. The source of urban noise worldwide is mainly caused by machines, transport, and public and private construction works among others. The World Health Organization (WHO) defines noise above 65 decibels (dB) as noise pollution. That classification doesn't differentiate the source of the sounds.

The propagation of sound with ranging impacts on the activity of human or animal life, some of which are disturbing to a degree. Poor urban planning may give rise to noise disintegration or pollution, side-by-side industrial and residential buildings can result in noise pollution in the residential areas.

Some of the main sources of noise in urban areas include loud music, transportation (vehicle traffic, rail, airplanes, etc.), lawn care maintenance (leaf blowers being the worst), construction, electrical generators, wind turbines, and people crowds.

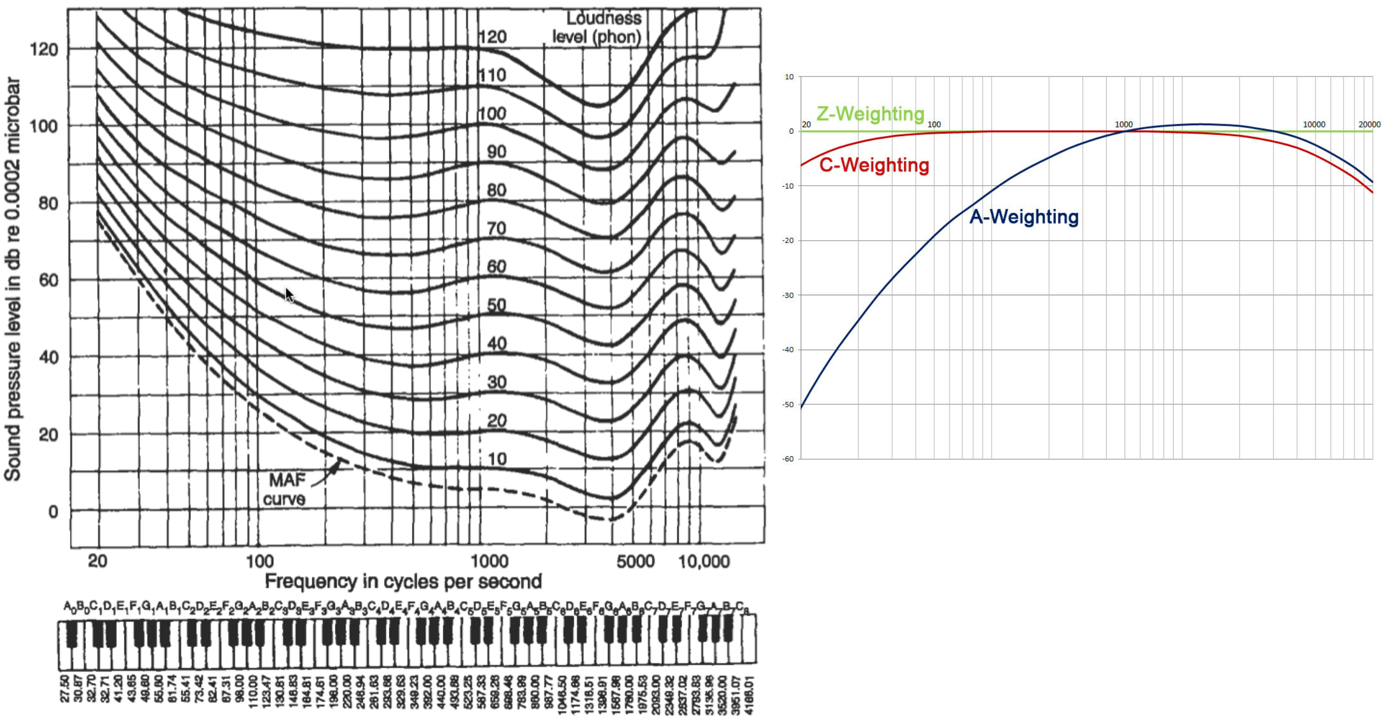
Documented problems associated with noise in urban environments go back as far as ancient Rome.

Research suggests that noise pollution is highest in low-income and racial minority neighborhoods.

Our intention with this paper is to approach the issue or urban sounds from an engineering perspective that is far away from the term sound pollution. We don't think all sounds over 65 dBA are pollution like the WHO, on the contrary we think many urban sounds under 65 dBA can be "unwanted" and/or "disturbing" and some others over that level part of the Urban Soundscape.

The main problem here is that sounds until now are being classified and characterized only by its intensity, and the equal loudness tables such as the one shown below, that are the basis of the weighting scale of the Sound pressure Level in Decibels.

That is the only one to model for sounds today. The Sound Pressure Level.



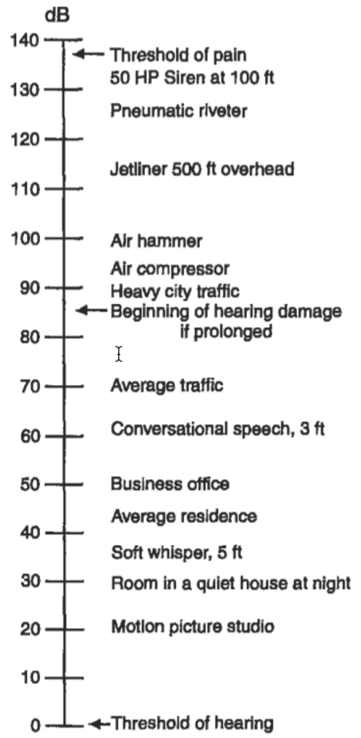
Equal Loudness contours and the A weight that compensates the human ear lack of linearity with sound exposure.

From the authors’s point of view none of the previously mentioned approaches up to date serve the purpose of create a good model to characterize and classify urban sounds.

1.- Measuring sounds

State of the art

The world's first practical sound level meter, was released in 1960 and developed by the Danish company Brüel & Kjær.



A typical sound meter is composed of different electronic parts. A. microphone is the transducer converting the pressure waves into electrical signals. This electrical signal is converted to Direct Current (DC) using a Root Mean Square (RMS) rectifier that is linear in voltage so it is passed to a logarithmic circuit to produce the logarithm scale. As shown at the right graph.

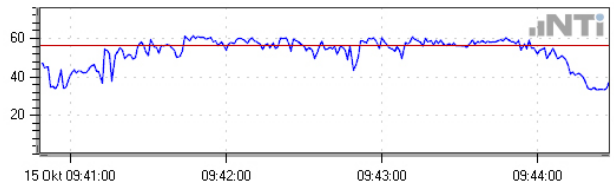
The threshold level of 0 db is defined with a sound pressure of 20 microPascals.

The logarithm is base 10 meaning 20 dB is a 100 times sound level difference because it has two zeroes.The decibel is, in a sense, not a unit, it is simply a dimension.

In 1980, Britain's Cirrus Research introduced the world's first handheld sound level meter to provide integrated Leq and sound exposure level (SEL) average measurements.

Leq is defined as the steady sound pressure level which, over a given period of time, has the same total energy as the actual fluctuating noise. It is also known as the equivalent continuous sound level, or the time-averaged sound level.

So Leq is a form of time weighting that is easier to read on a display than the instantaneous sound level. In the image at the right the flat red line has the same energy that the always fluctuating noise instantaneous noise levels.



In 2003 the combined standard IEC 61672 was published.

Since then, the Leq time averaged sound Pressure level has been the standard, that everybody follows to measure the sound exposure.

Is Leq the right measure for urban sounds?

The authors of this paper believe that Leq is an outdated standard to:

- Measure the exposition to "unwanted" and/or “disturbing” noise
- Even less adequate to create a model for urban sounds

Some simple questions and their common sense answers resolve the confusion that may be created at this point:

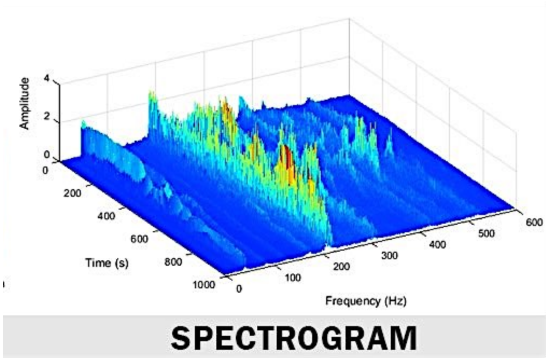
- Are all the sounds the same if they have the same Leq?
- Can be the aggressiveness of the sound (remember "unwanted" and/or “disturbing”) measure or even be modeled by measuring its average SPL i.e the Leq?

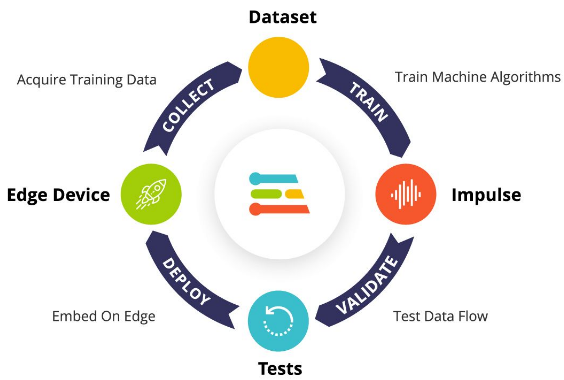
Leq from a technological perspective

The historical reason why Leq has been used as a way to evaluate sound exposure is vey simple: Until recently there was no other practical way to do it. Not anymore.

Today the have:

- Advanced microcontrollers with incredible computing power costing just over a few Euros that can process Fast Fourier Transform (FFT) algorithm and obtain spectrograms of the sound.
- Both in the amplitude (Y axis)/frequency (x axis) two axis domain and in tri-dimensional (waterfall) display being the Z axis the time.
- Artificial Intelligence tools, where complex spectrograms that need a human engineer interpretation can be now analyzed and characterized automatically and in real-time.
- An example of an A.I tool, that is used by researches is based on the Edge Impulse on-line machine learning platform.
- The process is shown in the image right. Machine Learning is used on this model to acquire data (sounds), train machine algorithms, validate the first results and deploy on the embedded edge, i.e right at the sensor.





Also, today we have MEMS (Micro Electro Mechanic System) transducers microphone that cost a few Euros and are linear up to an SPL of 160 db. Something impossible just ten years ago.

Lithium batteries have incredible power reserve per weight and provide power for portable equipment lasting autonomy per days.

Our intention is to create a practical design of a new type of sound sensor that evaluates the aggressiveness of the sound landscape and characterizes its properties far beyond the Leq

2.- Modeling sounds

2.1.- Sound modeling dimensions

Today sounds are only modeled by it amplitude over time. We say: "We have a 65dBA level" and everybody knows how the sound is. Right?. No, we think it's all wrong. The truth is that you have no idea of the properties of the sound just by knowing its level.

The sound property is today unidimensional. It is just the amplitude. We need to define a much richer new multidimensional approach in order to overcome the limitations of the SPL and the Leq standards.

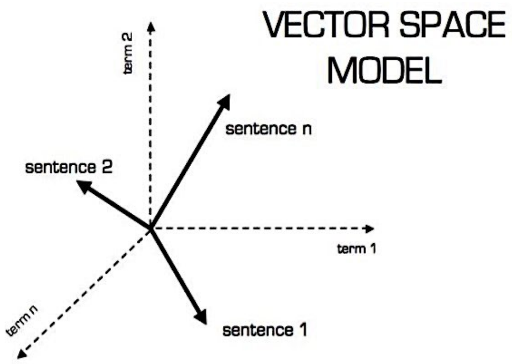
2.2.- Sounds as Vectors in the Space

We will be using a vectorial Space model to characterize the sounds.

Vector spaces are the generalization of the classic 2d and 3d vectors that we have studied from math in school.

We are talking about a definition field of R^n, cause each "dimension" or “variable" (amplitude, repetition, aggressiveness) is in the real number set R, and so if we have n variables, we have a R field for each.

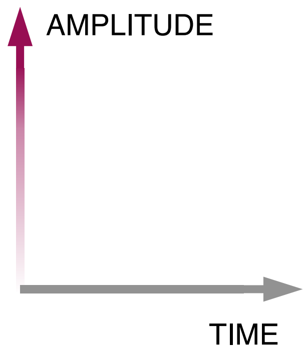
On 3-dimensional vector spaces we commonly use the names x, y and z for the variables and so this vector space I can be expressed as:

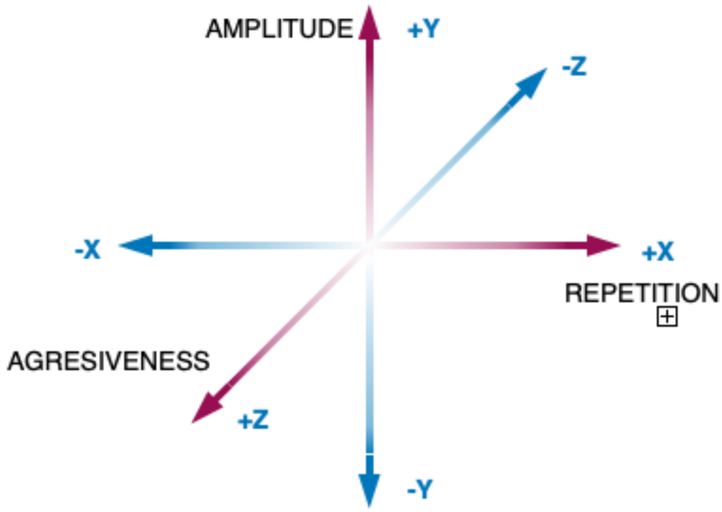


2.3.- Creating vectorial models for sound characterization

Using vectors different models can be created to model the sound in spatial models. A comparison is given as follows. The left image is showing the SPL unidimensional model, where the amplitude over time is the only variable used.

The right image is showing one of the many possible proposals for a new sound spatial model. In tis vectorial model sound variables such as the aggressiveness and the pulsing of the sounds (repetition rate) are shown using vectors.





2.4.- Creating urban sound indexes

We are here proposing the development of an urban sound index. We are explaining how a composed index is created following the analogies from other environmental indexes.

2.5.- Looking at what happened with the air quality Indexes

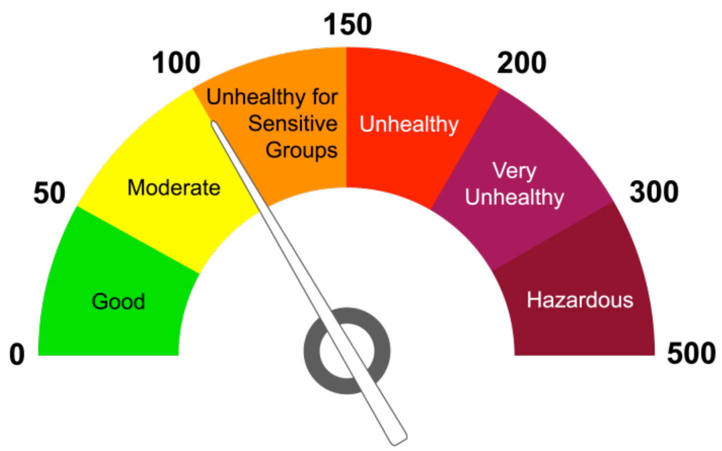
An air quality index (AQI) is used by government agencies to communicate to the public how polluted the air currently is or how polluted it is forecast to become. AQI information is obtained by averaging readings from an air quality sensor, which can increase due to vehicle traffic, forest fires, or anything that can increase air pollution. Pollutants tested include ozone, nitrogen dioxide, sulphur dioxide, among others.

The AQI is computed from the measure of different air variables such as Particulate matter suspended on the air, combustion gases and Volatile Organic Compounds (VOC).

AQI was born in China in the 90's to monitor the heavy pollution in Cities. In Europe AQI was adopted in 2007 and in November 2017, the European Environment Agency announced the European Air Quality Index (EAQI) and started encouraging its use on websites and for other ways of informing the public about air quality.

Today even Amazon's Alexa reports the Air Quality Index while asking any environmental data such as the weather forecast or the outside temperature.

One of the most popular Air Quality indexes is shown in the following image.



The question here is: Will be possible to illustrate the urban sound environmental quality by creating a compounded index such in that example?

Finally, we would like to mention that the principal authors of this paper have published research on the creation of compounded Indoor Air Quality Indexes as follows:

Title: [Indoor Air Quality (IIAQ) and Infection Probability Rate (IPR): Developing better spread risk models] - Biological and Chemical Research (ISSN 2312-0088, USA).

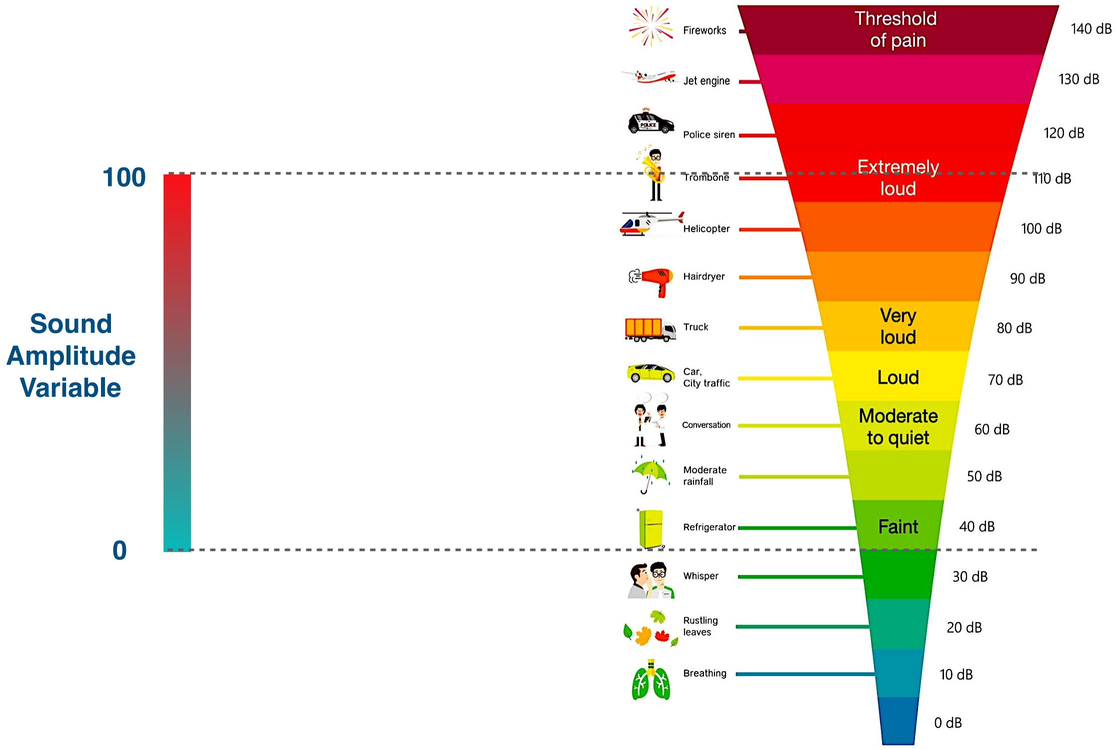
Check the link above for further reference about the creation of compounded indexes, and how these research can help for the development of sound indexes.

3.- The basis for the creation of Urban sound Indexes

We are proposing some variables that shall be accounted for in the development of urban sound indexes.

3.1.- Sound Amplitude (Loudness)

Yes, amplitude is the only sound variable that is taken into account today. We have already explained how the dBA is arranged to match the weighted physiological response of the human ear and how Leq is the averaged dBA level over an integrated period of time. The term amplitude or sound loudness doesn't need further discussion here. We will be however, using the amplitude here as different variable scale



The principle is simple. Sounds under 35 dBA are no perceptible in urban environments, while sounds over 110 dBA have an “overdrive” level for the human ear.

The computation of the amplitude variable can be easily done in C/C+, by using the mapping function.

```
int get_sound_level(void)
{
   int val;

   val = read_sound_db(0);
   val = map(val, 35, 110, 0, 100);
   return (val);
}
```

This simple function prints a 0 to 100 amplitude variable from the Sound Pressure level in dBA to be used in the development of compounded sound index. The lower and upper levels of 35 dBA and 110 dBA are chosen to be practical from the author's experience in providing a variable of amplitude in urban environments.

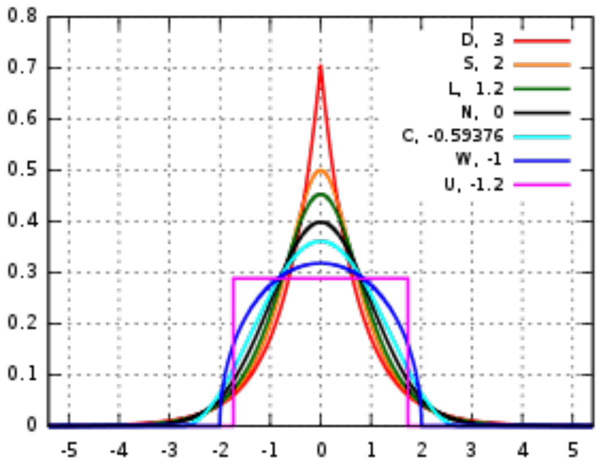
3.1.1.- Loudness: Scientific facts. **Hyperacusis** is a disorder in loudness perception. People suffering from hyperacusis may appear overly sensitive to a range of sounds, finding many noises unbearable and painfully loud.

For most people is the increased sensitivity to sound and a low tolerance for relatively loud environmental noise. Definitions of hyperacusis can vary significantly; it can refer to normal urban noises being perceived as: loud, annoying, painful, fear-inducing, or a combination of those.

3.2.- Sound Aggressiveness

In probability theory and statistics, kurtosis (meaning from greek "curved, arching") is a measure of the "taildeness" of the probability distribution of a real-valued random variable in this case sounds.

Kurtosis describes a particular aspect of a probability distribution. The more concentrated is the distribution the larger is the Kurtosis.



Kurtosis is calculated by: $$\mathrm{Kurt}[X] = \frac{\mu_4}{\sigma^4},$$

where µ4 is the fourth central moment and σ is the standard deviation of a function X.

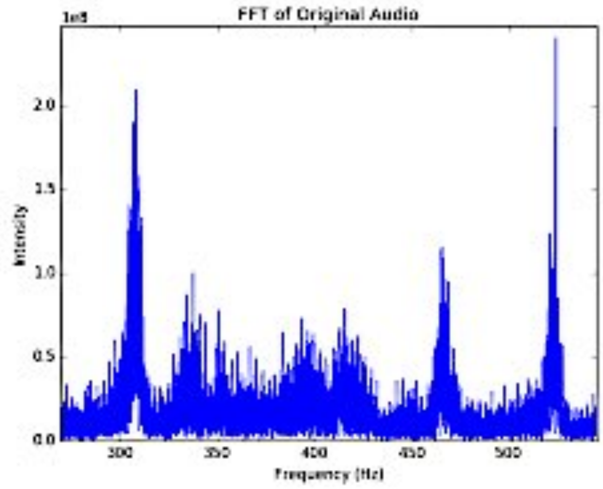
Kurtosis is a useful measure of whether there is a problem with outstanding values in a data set.

Larger kurtosis indicates a more serious outstanding problem, and here we are using Kurtosis function to identify aggressiveness of the sounds. Here is how:

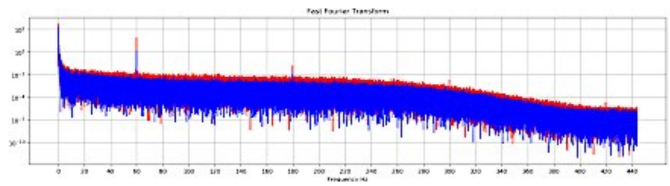
Frequency distribution of the sounds can be obtained by using the Fast Fourier Transform. FFT is an algorithm that translates the amplitude domain into the frequency domain.

More concentrated frequency distributions correspond to more aggressive sounds, as it is shown on the upper right image.

On the contrary flatter distributions correspond to pleasant, non-aggressive sounds, as shown on the lower right image.



Aggressive sound identified by the concentration of close frequencies (High Kurtosis)



Pleasant sound identified by the low concentration of close frequencies (Low Kurtosis)

Kurtosis can be calculated in C/C++ programming language by calculating Δ (delta) as the standard deviation.

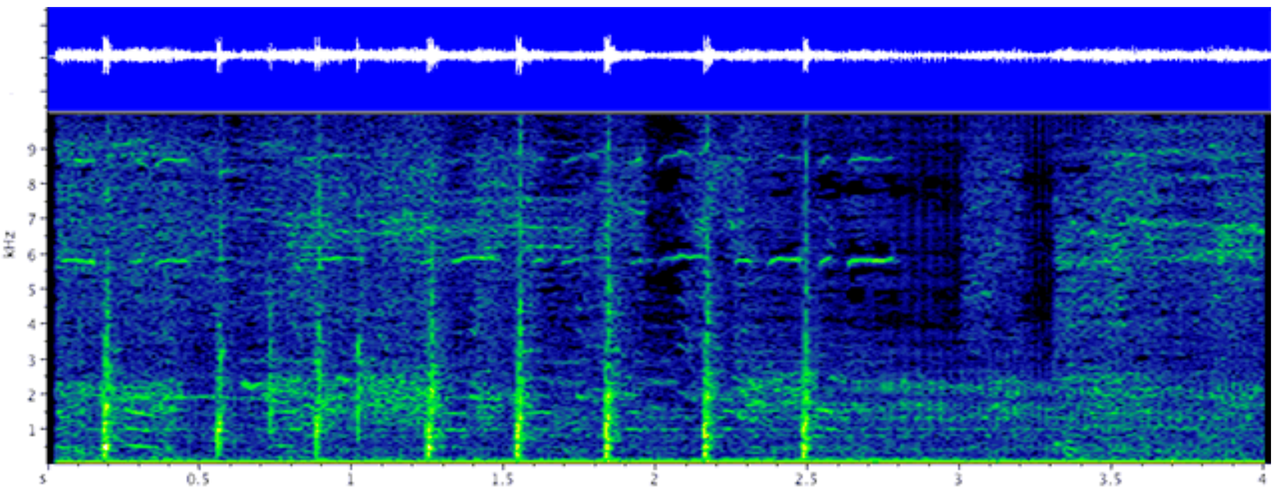
There are many libraries in C/C++ available as public domain that can be used for the purpose of computing Kurtosis in sound embedded sensors.

3.1.1.-Aggressiveness: Scientific facts: **Misophonia**, also called selective sound sensitivity syndrome, is a condition in which certain sounds trigger an outburst marked by irritation, anger, or aggression. People with misophonia react in an extreme and often emotional way to certain "trigger" sounds. Misophonia is not an auditory or psychiatric disorder.

3.3.-Sound Repetition: Roughness

We all know that hated sounds are often repetitive in nature. Sound amplitude is not the only parameter that changes when we increase vocal sound levels. Another important emerging feature is roughness, an acoustic texture that arises from fast repetitive acoustic transients.

Although the delimitation of the roughness range—whether psychoacoustic or perceptual—may slightly vary depending on experimental settings, empirical observations consistently suggest that sensory systems and perception are exceedingly well tuned to recurring temporal repetition or “pulsed" features in the 30–150 Hz range.



FFT Pulsed Sound waterfall spectrogram

Human sensory systems are not passive sensors or filters but instead display nonlinear properties that constrain the way we perceive and process incoming inputs.

Fast repetitive modulations produce “temporally salient” flickering percepts (e.g. strobe lights, vibration, and alarm or pulsed sounds, which efficiently capture attention, generally induce rough and unpleasant sensations, and elicit avoidance.

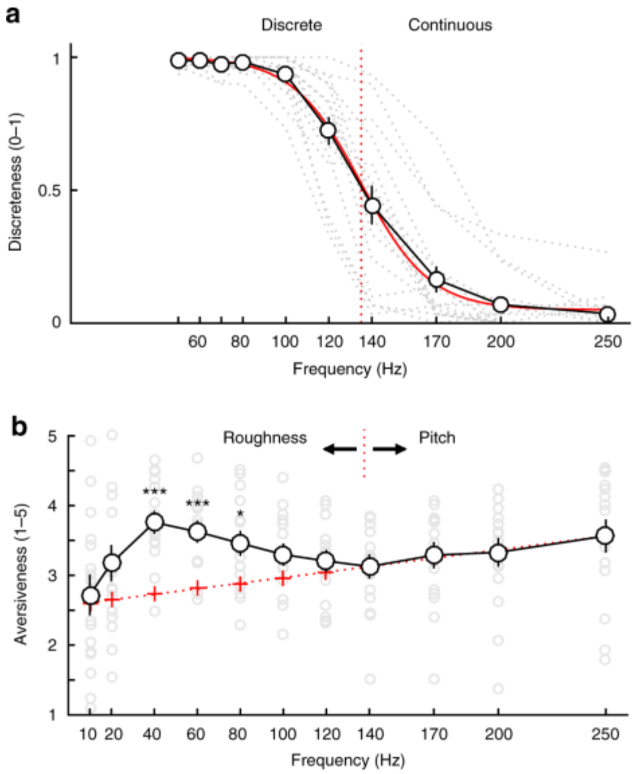
The graphs at the right are showing the studies of Luc H. Arnal et al. *"The rough sound of salience enhances aversion through neural synchronization"*

In that research paper a subjective characterization of temporal salience was studied, establishing an interesting borderline in the region of 150 Hz between discrete and continuous (time series) signal or sounds.

As a result the subjective transition between discrete(rough) and continuous (pitch) was determined.

The roughness or aversion was detected in the discrete region with peaks around 40 Hz and 60 Hz to 80 Hz.

The lower graph at the right is showing a red line marked with crosses in the same color. The roughness is here quantified as the excess from that line to the perceived sound roughness from 10 Hz to 140 Hz.



3.3.1.-Repeated or pulsed sounds: Scientific facts.

Entrainment, also referred to as brainwave synchronization or neural entrainment, refers to the observation that brainwaves (large-scale electrical oscillations in the brain) will naturally synchronize to the rhythm of periodic external stimuli, such as flickering lights, sounds (speech, music, noise) or tactile stimuli.

Researchers have found, for instance, that acoustic entrainment of delta waves in slow wave sleep had a well being effect in healthy individuals.

On the contrary amplitude modulations in the roughness range (30–150 Hz) produce aversion to such pulsed sounds.

By measuring subjective aversion to repetitive acoustic transients, researchers identified a nonlinear pattern of aversion restricted to the roughness range.

Using human intracranial recordings, we show that pulsed sounds synchronize activity throughout superior temporal regions, subcortical and cortical limbic areas, and the frontal cortex, a network classically involved in aversion processing. That proves that auditory aversion works by through spreading of neural synchronization.

3.4 Summary and recapitulation

Three variables of the urban sounds have been proposed for automated characterization purposes

- Amplitude/ Loudness
- Agresiveness
- Repetition rate/ Roughness

A vectorial space has been proposed to illustrate the sound multidimensional variables at-a-glance.

Scientific facts supporting the selection of these sound variables has been presented and reference to research regarding the variables is listed on the appendix

Algorithms to individually identify and measure the variables has also bee also proposed.

These are:

- A simple mapping of Logarithmic dbA Sound Pressure Levels (SPL),
- Kurtosis
- Fast Fourier transform (FFT)

Also the use of Artificial intelligence, using Machine learning platforms, such as Edge impulse has been proposed for automated combined (multidimensional) characterization of the urban sound on the edge, after training a model with audio data sets.

4.- Proposed embodiment. A smart sound sensor for urban sounds monitoring

The image in the following page is representing a proposed embodiment of the smart urban sound sensor. The sensor feature A.I. driven characterization of the sounds based on the vectors discussed before, that are Amplitude, Aggressiveness and Repetition rate.

<u>Hardware</u>

The hearth of the smart sensor is a powerful micro-controller that runs on a lithium battery, making the sensor extremely portable. A small solar cell replenishes the battery and a external 12 to 5 Volt input for extra recharging power will be available.

Several serial ports from the micro-controller connect the transducers or sensors. I2S is used for sound from digital output MEMS microphone. An I2C serial port is use to connect a geolocation device such as GPS. The same I2C port with a separate address, is used to connect external sensors for example environmental. With this add-on we can measure other bottles such as temperature humidity barometric pressure uneven air quality.

The micro-controller is connected via UART (Universal Asynchronous Receiver Transmitter) do a 4G/LTE transceiver that formers the data using a mobile network data service. This service is widely available in Europe for under €10 per month.

The proposed Device can we build on a small enclosure to be install vehicles bicycles or using urban furniture or fixtures such as public lighting bus stops or similar urban structures.

Firmware

The logic shall be written in C/C++ using RTOS (Real-Time Operating System). The data fed from the sensors is parsed, creating a string that is transmitted using Wi-Fi 4G/LTE connectivity via TCP/IP.

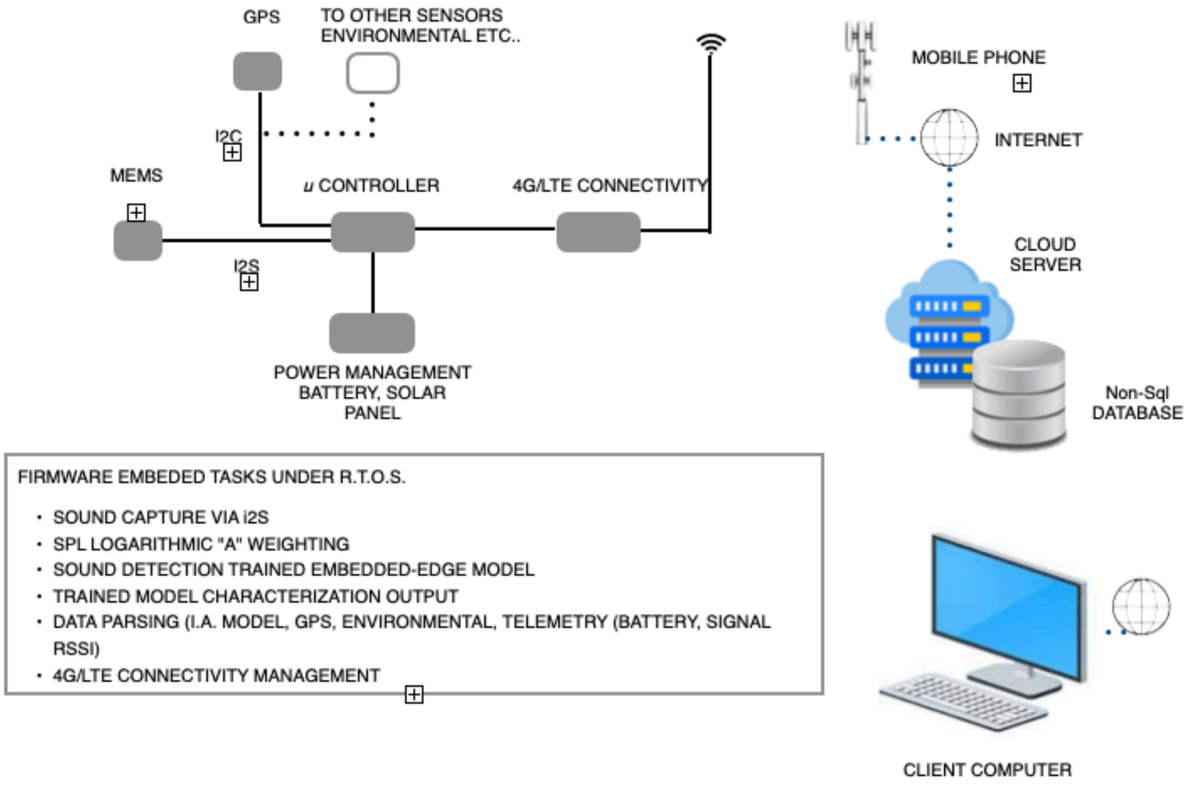


IMAGE OF A PROPOSED URBAN SOUNDS SMART SENSOR, CONNECTIVITY AND DATA PLATFORM

Server

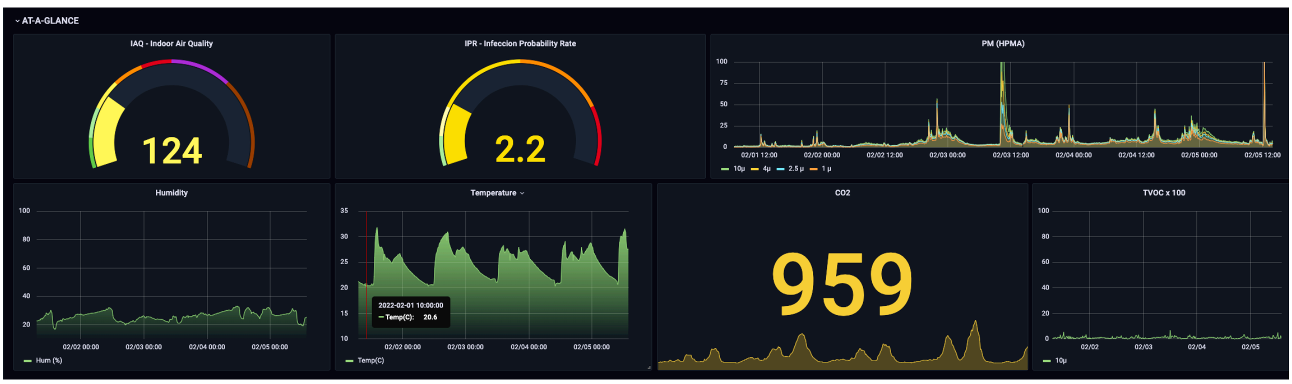
The data string is then organized before feeding the database using a JSON declarative language.

A non-SQL database is used to store the data. Non-SQL type databases offer a better search speed while providing historian reports when the amount of data stored is huge such in this case. The data is secured by installing an SSL certificate on the server.

Client

An agnostic client set-up was used from the beginning. The data stored in the database can be searched from any password-authorized device. A smartphone, computer, or tablet using any O.S. can be used for this purpose.

A GUI (graphic user interface) will be used to visualize the data, an example referring to air quality is shown.



Graphic User Interface (GUI) TELEMETRY AND SOUND LEVELS CAN BE DISPLAYED AS IN AIR QUALITY SERVERS

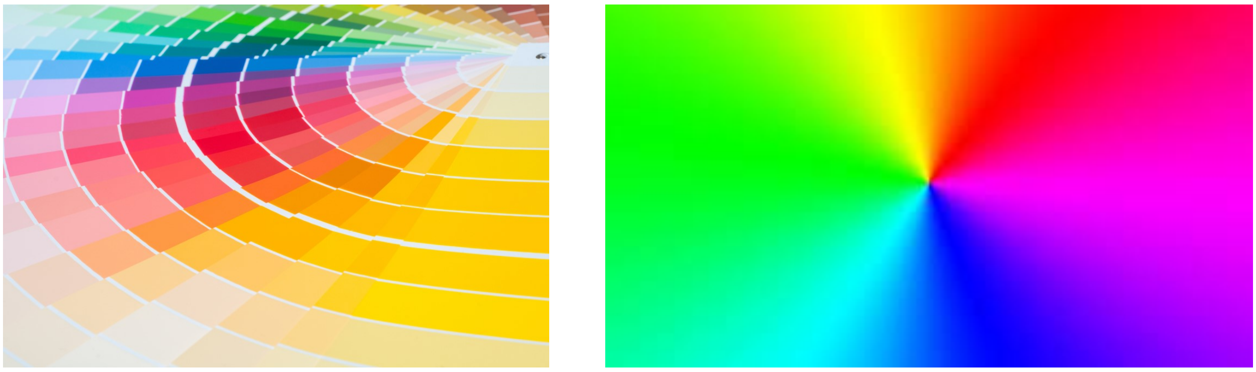
5.- Artistic interpretations of the Urban Sounds characterization.

Artistic representation of the urban sounds are possible after the sound has been identified and characterized.

Some possibilities are:

- Representing any of the sound vectors with colors
- Representing any of the sound vectors with images
- Representing any of the sound vectors with synthesized sounds
- Representing the Urban Sounds as a combination by using a different expression from each vector

For example the loudness or amplitude can be represented with colors while aggressiveness s represented by images or synthesized sounds. Imagination is the limit!



COLOR PALETTE EXAMPLES

The images before are showing as an example of color palettes. The right image corresponds to an RGB representation. RGB provides an easy representation of the colors from the digital encoding in 16 or 18 bits that is the standard for color representation.

Regarding sound we are proposing here they use of analog VCO (Voltage Controlled Oscillator) as a tool to create synthesized sounds from the characterization of the Urban Sounds. The digital levels can be used with analog VCO using a Digital to Analog Converter (DAC).

SYNTHESIZER ANALOG VCO STUDIO OF ONE OF THE AUTHORS

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  DOI: 10.2752/174589210X12668381452845
  A useful literature review, this text summarizes the adoption of the concept of the soundscape in the interdisciplinary field of sound studies.
- **Schafer, R. Murray. *The Soundscape: Our Sonic Environment and the Tuning of the World*. Rochester, VT: Destiny Books, 1994.**

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- **Sterne, Jonathan. “Soundscape, Landscape, Escape.” In *Soundscapes of the Urban Past: Staged Sound as Mediated Cultural Heritage*. Edited by Karin Bijsterveld, 181–194. Bielefeld, Germany: Transcript Verlag, 2012.**

  Contextualizes Schafer’s notion of soundscape in the cultural and technological history of the 1960s and 1970s, focusing on the influence of hi-fi music technology.
- **Truax, Barry, ed. *The World Soundscape Project’s Handbook for Acoustic Ecology*. Vancouver, Canada: ARC, 1978.**

  This book sets out the World Soundscape Project’s agenda for acoustic ecology
- ***The rough sound of salience enhances aversion through neural synchronization. Nature Communications Aug2019 LucH. Arnal et Al***

  Interesting paper about sound roughness and entrainment
- ***Sounds associated with aggression. www.dosits.org 2021. University of Rhode Island USA***

  About the character of mammal marine sounds
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