MADRID
inter.noise 2019
June 16 - 19
NOISE CONTROL FOR A BETTER ENVIRONMENT

Real time 3D environmental noise monitoring and mapping using large-scale internet of things

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ABSTRACT

European and Swiss regulations regarding monitoring of the environmental noise pollution require the determination of the noise level over large territories, with a high level of accuracy, considering the 3D topology. To date this is generally done by numerical simulations fed by a limited number of measurements, usually performed manually or with a network of few connected expensive sonometers, used to calibrate the models.
We present an alternate approach based on the use of large population of smart autonomous noise sensors based on inexpensive MEMs microphones and connected to a LoRaWAN™ wireless communication internet of things network. A measurement campaign involving more than 900 sensors have been deployed in the city of Carouge at various heights ranging from 3 to 15 meters, over a period of 1 year without need for replacing sensors' batteries. From the analysis of the continuous noise levels records, we show that the generated large volume of data makes possible the determination of standard noise indicators with high accuracy, and also allows real time monitoring of their evolution all over the city. This approach will drastically improve cities' strategies and policies regarding environmental noise reduction.

Keywords: Noise, Environment, Annoyance, Measurement, IoT, Internet of Things, LoRaWAN, LPWAN
I-INCE Classification of Subject Number: 72

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1. INTRODUCTION

During the keynotes of Noise in Europe conference [1], European commission exposed their findings of the evaluation of the Environmental Noise Directive (END) [2] and activities aimed at reduction of noise pollution in the Union. Despite a general consensus about the good quality of the END, the progresses in noise measurement and reduction were considered slow, and the need for a harmonized assessment of noise among the Union was expressed.

European and Swiss regulations regarding monitoring of the environmental noise pollution require the determination of the noise level over large territories, with a high level of accuracy, considering the 3D topology. To date this is generally done by numerical simulations fed by a limited number of measurements, usually performed manually or with a network of few connected expensive sonometers, used to calibrate the models. The complexity and cost of those type of measurements has led to research experiments based on volunteered geographical information (VGI) gathering noise level from mobile phones measurement [3][4]. Though promising, those methods suffer from limited control about where and how the measurements are performed.

We present an alternate approach based on the use of large population of smart autonomous noise sensors (based on inexpensive MEMs microphones similar to those used in mobile phones) wirelessly connected to an internet of things infrastructure. Those sensors can easily be installed at the most pertinent locations identified by experts from the field, and the way their measurement is performed is well known and characterized.

In a first part, we describe the connected sensors architecture and performances. In a second part we explain the principles of the IoT communication, and the characteristics of the deployment made in the city of Carouge, Switzerland. In a third part, we present the preliminary results of a 1-year measurement campaign.

2. THE AUTONOMOUS NOISE SENSOR (ANS)

2.1 Architecture

The autonomous noise sensor performs 2 main functions. It is capable of making an accurate and continuous measurement of the environmental noise in its vicinity. And it also capable to transmit in real time the statistics of the measurements to a wireless IoT network. Figure 1 here below shows the architecture of the noise sensor that encompasses:

- A microcontroller which constitutes the heart of the embedded system, controls all the other blocks and makes it possible to perform the necessary signal processing.
- A power supply unit with a battery and electronic management of the supply voltage
- A memory for storing the measured data for the case where retransmissions would be necessary

- A wireless communication block containing a LoRa™ chip and an antenna to transmit measured data through to the IoT infrastructure and/or receive instructions from applications and network.
- A physical measurement block consisting of the MEMs microphone and an associated memory for storing the calibration data related to the microphone on to a separate daughter board to simplify maintenance.

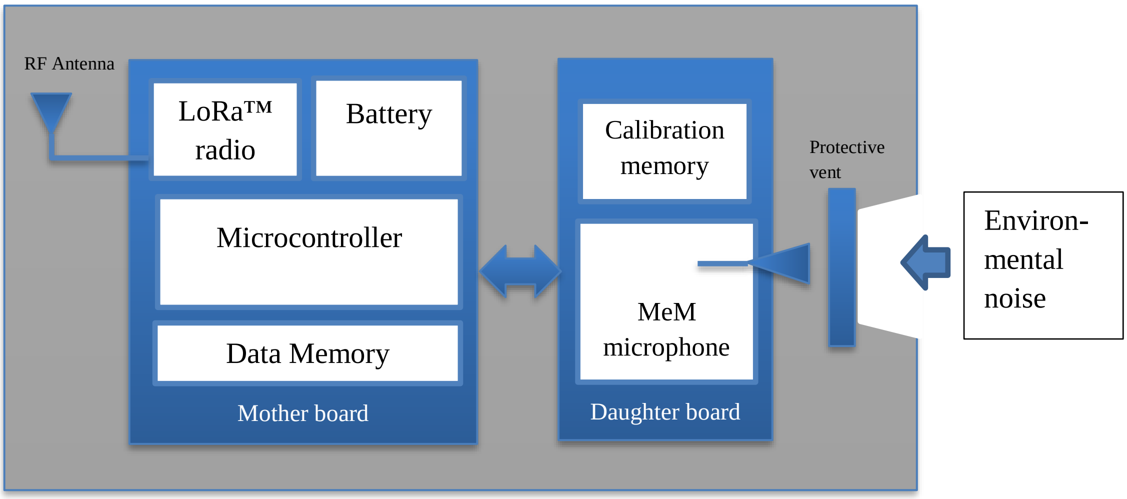

Figure 1: Synoptic architecture of the autonomous noise sensor

The figure 2 here below presents a view of the ANS where the base of the enclosure holds the mother board with the battery and the little black antenna at the top. The cover holds the measurement daughter board with the MEMs.

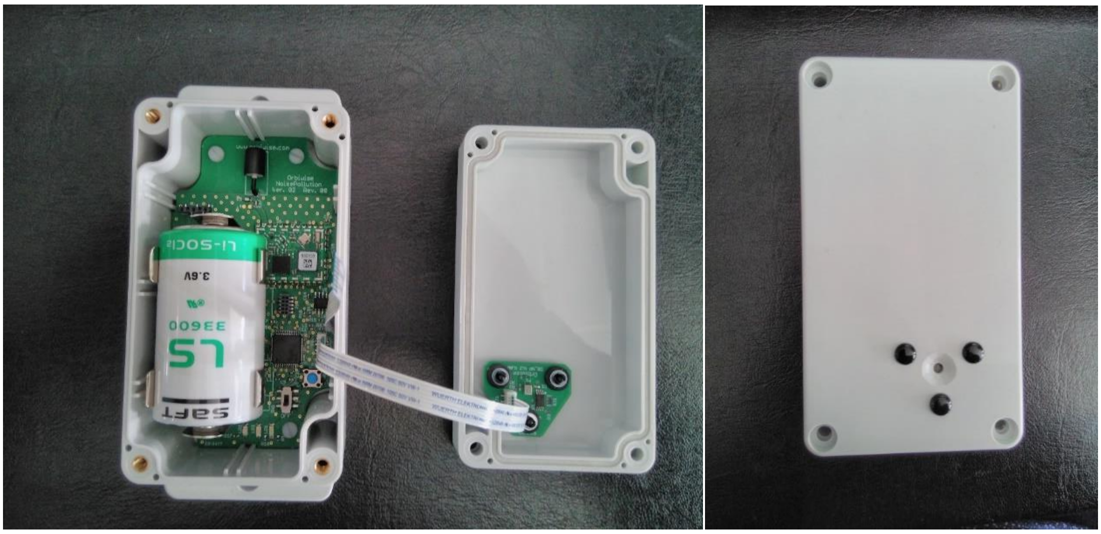

Figure 2: Inner and top view of the autonomous noise sensor

2.2 Characterization of the sensors

The ANS has been designed with the objective to perform linear measurements in the range of 40dB to 100dB for instantaneous maximum noise levels. The MEMs microphone provides a digital output signal (PDM type) that is then processed according the scheme shown in figure 3.

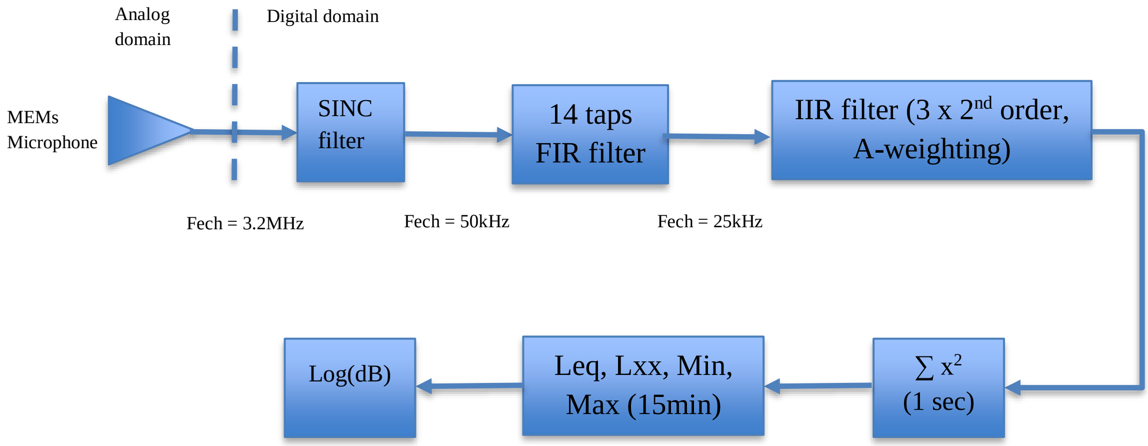

Figure 3: Signal processing of the MEMs microphone's output signal

The system is easily parameterized. In this project, every 15 minutes, the A-weighted sound pressure level $L_{eq,15min}$ is computed by the sensor and this statistical data is transmitted through the IoT network and stored (by the application and locally on the ANS'memory). The following percentile noise levels are also calculated and transmitted: L_{10}, L_{50}, L_{90} and L_{95} as well as the L_{min} and L_{max} levels.

Several sensors were characterized at the Swiss Federal Institute for Metrology (METAS) in an anechoic chamber like shown on figure 4. The measurements results are summarized here below:

1) relative linearity error is between 0 and less than 0.2dB for noise levels from 50 to 95 dB (measurement done at 1kHz)

2) the frequency response measured at 70 dB deviates by +/- 4 dB within the frequency range from 100Hz to 10kHz.

3) the maximum absolute value of the difference between measured sound levels at any two sound-incidence angles within +/- 90° from the reference direction is better than 3dB for low frequencies (125Hz to 1kHz), and better than 7dB for higher frequencies (2kHz to 15kHz).

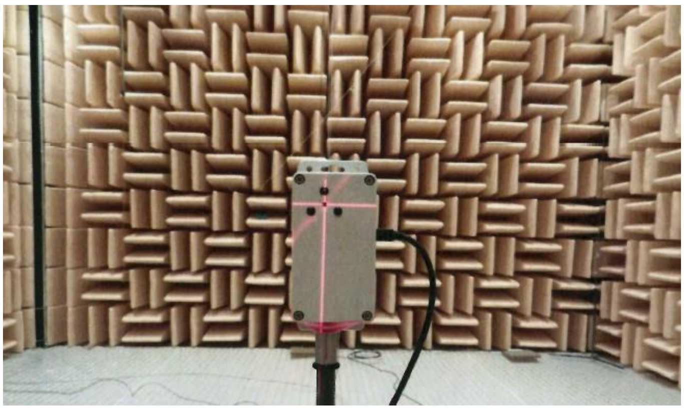

Figure 4: Characterization of the ANS in an anechoic chamber

The ANS do not meet class 1 or 2 requirements from the IEC 61672-1 standard, however they perfectly match their primary purpose within the scope of this project, that is to measure road traffic noise with levels ranging from 40 to 80 dB typically, with classical spectra.

Additional measurements were done placing side by side the autonomous noise sensor and a class 1 sonometers in real traffic conditions. The results showed that the measurement differences between both systems were below 0.5 dB, with no systematic error.

3. MEASUREMENT CAMPAIGN

3.1 Principles of the IoT communication

The ANS is capable to wirelessly communicate with any IoT network infrastructure of the type of Low-Power Wide-Area Network (LPWAN). For this project, the communication technology was chosen to be LoRa™ for the physical layer and LoRaWAN™ for the communication protocol, operating in unlicensed frequency bands [6]. Gateways have been installed at high points in Carouge city, to cover the area of interest.
As shown in figure 5, the noise sensors autonomously measure and transmit their data. The gateways in vicinity of the sensors (up to 15km in open area) receive the packets and transfer them to the network server. The network server pushes the data to the user portal applications for post-processing and display.

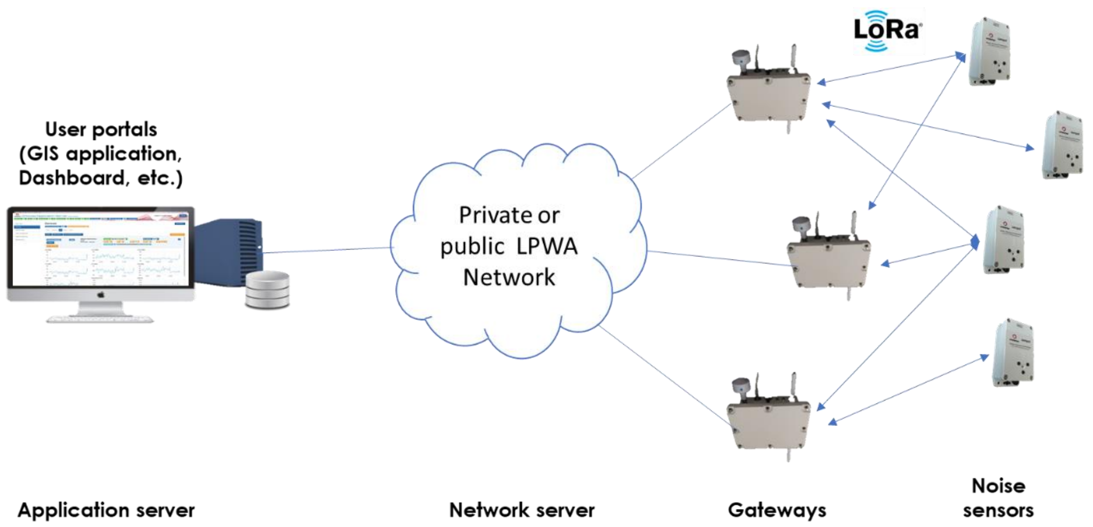

Figure 5: Synoptic view of the low-power wide-area IoT network (LPWAN)

3.2. Deployment of ANS grid

Started in October 2017, the deployment has occurred in several phases. More than 500 sensors have been first installed in the streets of Carouge city, at a fixed height of 3m above the ground. Those sensors have been placed in front of building, on the facades, and most often on gutters as shown in figure 6. Then, 400 more sensors at higher heights (6m and 9m), which will allow 3D characterization of road traffic noise within the city.

Figure 6: View of ANS installation on the buildings' facades

On figure 7, we show a map of the locations of the sensors in the streets of Carouge city. Groups of sensors vertically aligned and installed at 3, 6 and 9 meters are represented by the same single marker.

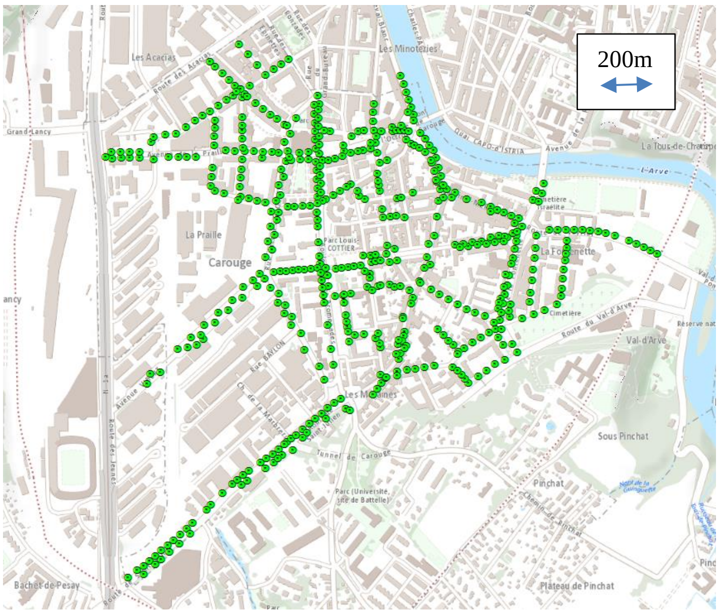

Figure 7: Map view of the location of the ANS deployed in the city of Carouge

4. ROAD TRAFFIC NOISE MEASUREMENTS

4.1 Examples of noise measurements from an individual sensor

The ANS measures the overall ambient noise; hence it captures all sort of noise in vicinity (traffic noise, sirens, conversations, etc.). So, all the sensors have been carefully positioned to locations where they would be exposed to traffic noise mostly. It should also be emphasized that only averaged data are recorded every 15min, and that these electronics devices have not been designed to record any voice type of signal. A filtering algorithm is implemented at the sensor level to discard abnormal data from calculations.

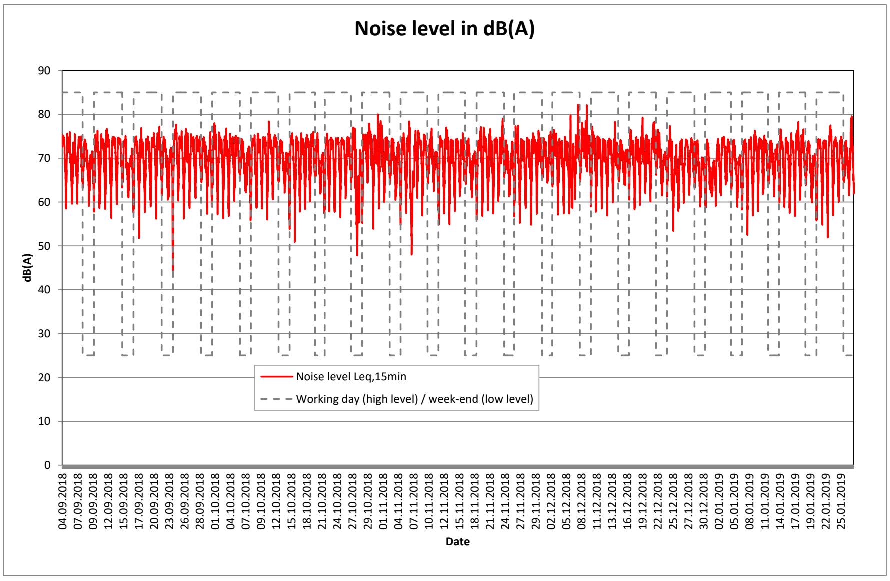

Figure 8: Noise level $L_{eq,15min}$ measured on one sensor (example)

Figure 8 shows an example of the noise level $L_{eq,15min}$ which has been measured from 4th of September 2018 to 25th of January 2019 (21 weeks of measurements). The dotted line shows the working days (high value) and the week-ends (low value).

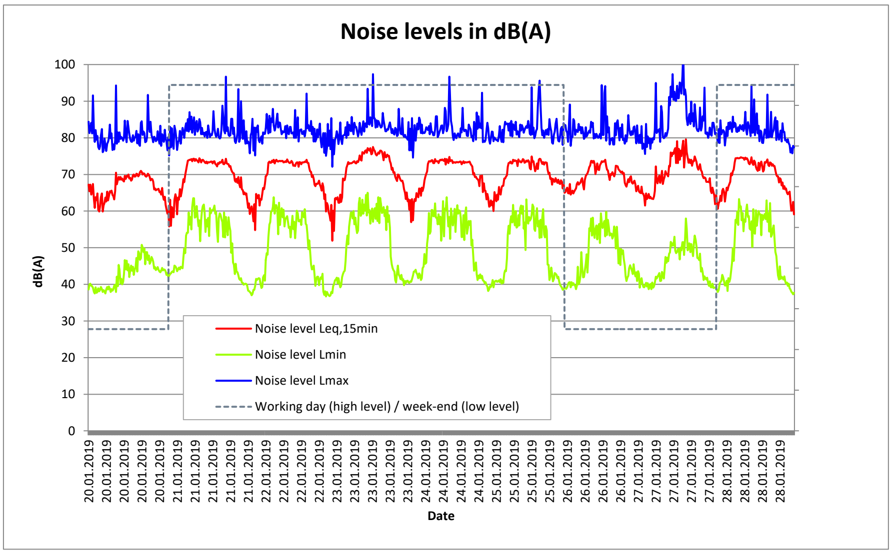

Figure 9: Noise level $L_{eq,15min}$ measured on one ANS: a week close view

Figure 9 shows a close view of the signal represented on Figure 8. The red, green and blue lines represent $L_{eq,15min}$, L_{min} and L_{max} respectively. This figure shows that the noise level characteristics are quite regular during working days, and noisier during the week-end.

4.2 Noise indicators

According to the Noise Abatement Ordinance (NAO) from the Swiss Confederation [5], road traffic noise needs to be calculated for an average day (from 6am to 10pm) and an average night (from 10pm to 6am) periods. Figure 4 shows the average sound level for the day periods corresponding to the data represented in Figure 10.

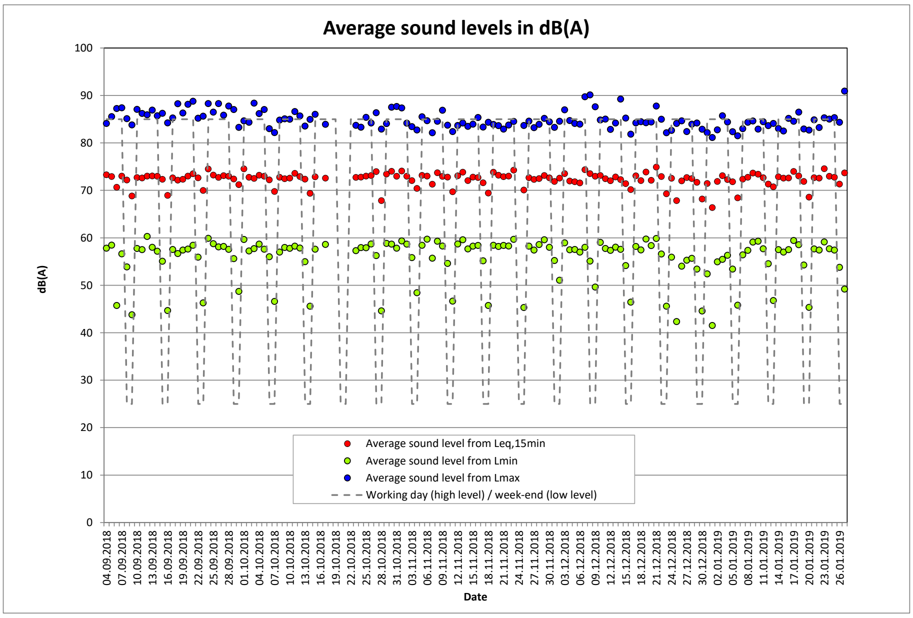

Figure 10: Average sound levels for day periods calculated from L_{max} (blue dots), $L_{eq,15min}$ (red dots) and L_{min} (green dots)

On figure 10, the average sound level calculated from the $L_{eq,15min}$ data is visibly stable over time (the standard deviation is less than 1.3dB). The average sound levels calculated on the L_{min} data show that Sundays are much quieter than other days of the week, which is to be expected (values close to 45 dB to be compared to 57dB). The same data reveals the end of the year holiday as well, which is visible by a slight drop of the curve at the last two weeks of 2018. The mean values are calculated according to the following equations:

$$L_{k,day} = 10\log\left(\frac{1}{N_{k,day}}\sum_{i=6h}^{21h45} 10^{L_{15min}(k,t_i)/10}\right) \qquad \text{(Equation 1)}$$

with $N_{k,day}$ the number of 15 minutes periods with valid data (maximum number of 64) and $L_{15min}(k,t_i)$ the data measured by the sensor #k at the time t_i.

Similarly the night average sound level is calculated according to:

$$L_{k,night} = 10\log\left(\frac{1}{N_{k,night}}\sum_{i=22h}^{5h45} 10^{L_{15min}(k,t_i)/10}\right) \qquad \text{(Equation 2)}$$

with $N_{k,night}$ the number of 15 minutes periods with valid data (maximum number of 32) and $L_{15min}(k,t_i)$ the data measured by the sensor #k at the time t_i.

Average sound levels are recorded under the condition that at least 80% of the $L_{eq,15min}$ data are valid. If it is not the case, a dummy value of -1 is assigned to the averaged parameters, as it can be seen in the figure 10.

An hourly average can be obtained for each of the 96 quarters of a full day. The figure 5 shows the results obtained for the $L_{eq,15min}$ data represented on the figure 9.

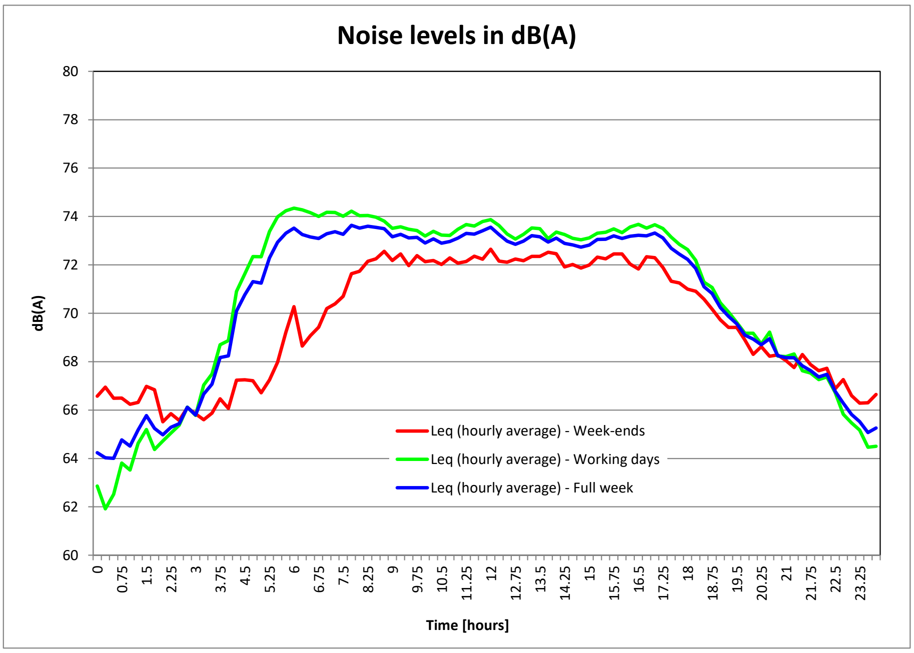

Figure 11: Hourly average levels calculated from $L_{eq,15min}$

The data represented in figure 11 take into account 140 days of measurements and exhibit several characteristics: 1) the noise level increases rather sharply during working days (reaching half of the maximum daily noise around 4am), whereas this increase is much smoother during the week-end (half of the maximum daily noise is reached around 6am), 2) the noise level decrease is much smoother than the noise level increase (half of the maximum daily noise is reached around 7pm). Calculation of this type of curve has been done on different sensors located in different places of the city. First indications show that sensors can be grouped by families sharing same types of curve characteristics (shape, slopes and amplitudes). Work is on-going to better characterize these properties and to correlate them with parameters like type of roads (local, collector/distributor, and arterial roads) or topography of the urban environment near the sensor.

Figure 12 represents a map of the 520 sensors currently working. The X and Y axis represent the Swiss grid coordinate systems and the dots represent the $L_{k,day}$ values (on a color scale) of the kth sensor. The map represents the layer of sensors which have been placed 3m above the ground level. Work is ongoing to produce more post-processed data from higher levels (6m and 9m). As most of the sensors were positioned along the streets of the city, the map of the figure 6 allows recognizing the main streets of Carouge. As it can be seen, noise level varies quite significantly from streets to streets highlighting the ones with busier traffic. Work is on-going to extract the emission levels of each of the street where the sensors are installed. The high number of sensors makes now possible to determine accurately road noise emission characteristics, by averaging a very large number of data. Another great benefit from this measurement approach is that it allows an accurate determination of the day and night average noise levels difference. This information is usually difficult to get from standard measurements done with sonometers. The continuous measurements done simultaneously over a large area makes now possible monitoring of the noise level variation with time and geography. This opens very interesting opportunities to identify area needing noise mitigations measures, or to evaluate their efficiency over time.

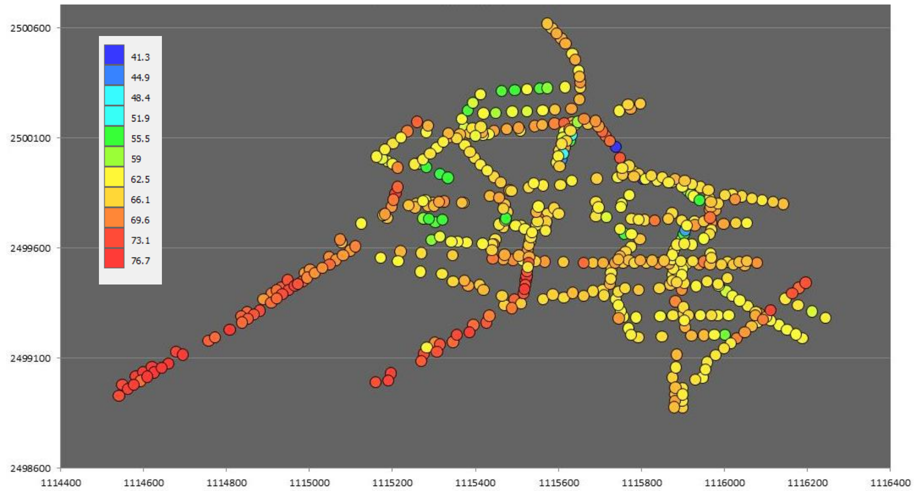

Figure 12: Average sound levels in dB(A) for the day periods calculated from $L_{eq,15min}$ and represented by color code (units in dB(A)) on a X-Y coordinate system

5. CONCLUSIONS

In this work, the concept of internet of things have been applied to environmental noise measurement. An autonomous noise sensor have been designed to be capable of doing continuous and accurate noise measurement over a one year duration on a type-D battery, sending its data through a wireless IoT communication infrastructure. Those sensors can be installed almost anywhere and are the basis for a ubiquitous monitoring of the environmental noise in the cities.

A measurement campaign involving more than 900 sensors have been deployed in the city of Carouge, with sensors being at various heights ranging from 3 to 15 meters, over a period of 1 year without need for replacing sensors' batteries. From the analysis of the continuous noise levels records, we show that the generated large volume of data makes possible the determination of standard noise indicators with high accuracy, and allows real time monitoring of their evolution all over the city. Another great benefit from this measurement approach is that it allows an accurate determination of the day and night average noise levels difference. This information is usually difficult to get from standard measurements done with sonometers. The continuous measurements done simultaneously over a large area makes now possible the monitoring of the noise level variation in real time. This opens very interesting opportunities to identify area needing noise mitigations measures, or to evaluate the efficiency over time of noise reduction measures like low noise asphalts replacement or traffic reorganization. This approach will drastically improve cities' strategies and policies regarding environmental noise reduction by shortening the cycle of noise cadaster measurement from 5 years to less than half day (to average the 15 minutes periods continuous measurement), and showing in real time the impact of noise reduction corrective measures, allowing a more reactive, flexible , hence less risky approach to this major health and economic issue.

6. ACKNOWLEDGEMENTS

This work was supported by grant UTF 495.25.14 from the Swiss Federal Office of Environment. We would like also to warmly thank the city of Carouge for hosting this large experiment, and METAS for the characterization of the ANS and for providing thoughtful feedback.

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