MOBILE ACOUSTIC SENSOR NETWORK FOR AUTOMATIC NOISE MAPPING: PROJECT MASANOM

Andreu Balastegui[1], Teresa Pàmies[1], Guillermo Quintero[1], Franck Vásquez[1], Ruikang Zhang[1]

[1] *Centre Avançat de Tecnologies Mecàniques (CATMech), Universitat Politècnica de Catalunya- BarcelonaTech (UPC), Colom 11, 08222 Terrassa, Spain*

This contribution has been accepted based on the submitted abstract. The submitted manuscript was not reviewed and is reproduced here without edits or corrections by the conference board. Neither the EAA nor the AAA take responsibility for its contents.

Abstract

The objective of the project MASANOM is to automatically plot noise maps with georeferenced data sent from low-budget autonomous noise measurements stations installed in low-background noise vehicles riding around the city. This method reduces significantly the cost of generating noise maps, thus, it is specially relevant for small cities or developing countries. However, there are several difficulties to overcome and computations that have to be performed to apply this system. First, the noise measurement station needs to have a GNSS and a communication system, while at the same time being energetically autonomous. This is achieved by greatly optimizing all of the computations to reduce its power use, and by using a solar panel and a vibration energy harvester to power the station. Second, the noise measurements taken at a position in the road have to be corrected and transformed to façade levels at 4 m height according to the European Directive 2002/49/EC, which is achieved with transfer functions obtained with fits from numerical simulations. Finally, the vehicle fleet size and routes have to be computed with traffic simulations to grant the spatio-temporal coverage required to produce accurate annual noise levels to plot a city noise map.

Keywords: *noise maps, mobile noise sampling, autonomous noise sensor*

1. Introduction

In order to compute the population exposure to environmental noise and to design and apply convenient action plans to reduce it, Directive 2002/49/EC [1] defines an environmental noise map as a picture of noise levels for different sources and time intervals. According to the Directive, since 2019 it is mandatory to compute noise maps by simulation, using the model CNOSSOS-EU (Common NOise aSSessment methOdS) [2]. However, a number of concerns have arisen regarding the simulation methods, since the results depend on the calculation procedure and the quality of the data required to develop the noise map. These shortcomings cause a significant loss of accuracy [3] that can call into question, both by the scientific community and the general public, any action plan designed as a result of the noise map [4].

Taking of direct noise measurements was also a valid strategy for producing noise maps and several cities do use data from direct measurements for controlling some discrete noise sources and also for population information purposes; the latter as a form of complementary information to that included in the environmental noise maps. However, the cost of taking direct measurements to produce a large-scale environmental noise map is too expensive to be carried out without a considerable reduction of the measurement effort, both in space and time scale, with the result being an unknown loss of accuracy.

The combination of a fixed sensor network of high communication power nodes and a mobile network of high processing power could help to reduce some of the previously mentioned shortcomings, whilst at the same time exemplifying most of the strong points of both networks [5], [6].

Within the MASANOM project, low-cost autonomous noise measurement stations have been designed and constructed, that will be moving around the city mounted in low-background noise vehicles, like bicycles or electric scooters from delivery companies or individual means of transportation, with the objective of automatically generating and updating noise maps based on direct measurements.

The use of these low-budget measurement stations will reduce the costs of creating noise maps, making them more affordable for developing countries where traffic noise is an important issue due to the presence of high-density agglomerations and the much older fleet of vehicles.

Corresponding author: *andreu.balastegui@upc.edu.*

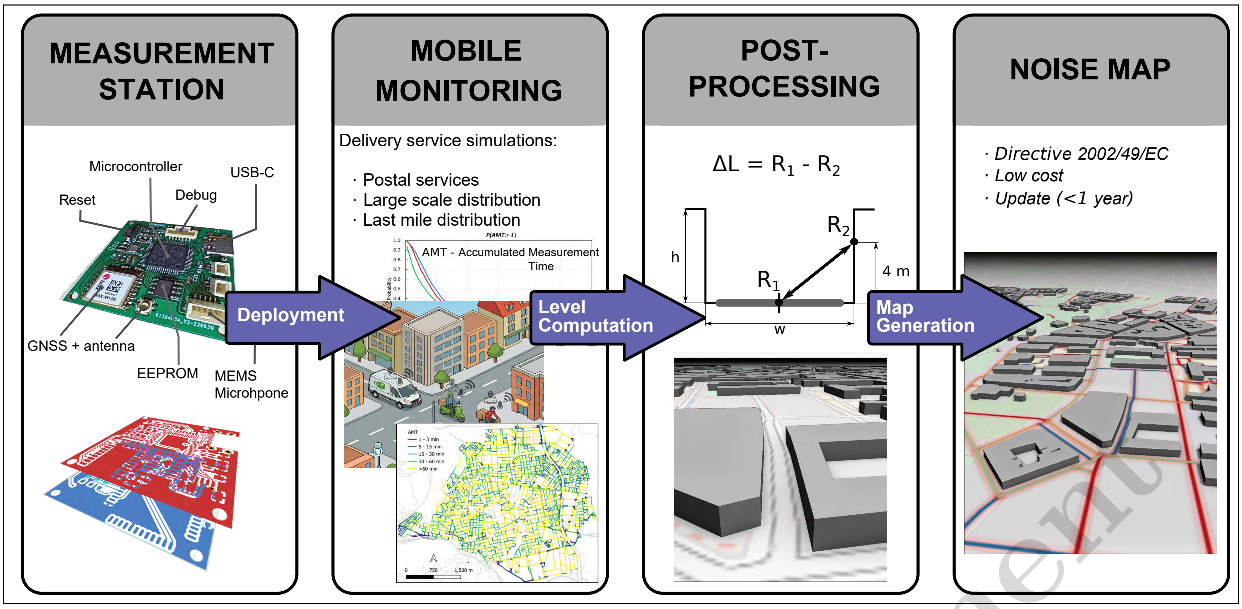

Figure 1: Schematics of the MASANOM project.

However, there are several difficulties that must be solved to obtain the annual values of L_{den} and L_{night} following the European Directive 2002/49/EC. Among others, there is the issue of the self-generated noise of the vehicle, noise source discrimination, sample aggregation, vehicle routes and estimation of façade levels.
In addition, from the hardware requirements, one needs a noise measurement station with geopositioning and communication capabilities that, at the same time, can be autonomous, so it has to be low-consuming and self-powered.
Fig. 1 presents the MASANOM project tasks that will be discussed in the following sections of the present paper:

- Details of the measurement station.
- Spatial and temporal sampling of the carrier vehicles.
- Estimation of façade levels.

2. Noise measurement station

The noise measurement station integrates a microcontroller, a MEMS microphone, a GNSS module for geopositioning, an IoT module for communications and an ultra low-power EEPROM, distributed as shown in Fig. 2. The total budget of a single measurement station is broken down in Table 1. In addition, a 3D printed case has been designed for the PCB and the battery, with a small pipe for the microphone and a fixation system to the vehicle.
The station measures A-weighted sound levels, L_{Aeq}, and one-third octave band spectra from 63 Hz to 10 kHz every 125 ms, in compliance with IEC 61260-1 [7]. After the microphone calibration, the accuracy of the noise measurement station is equivalent to that of a Class 2 sound level meter [8].

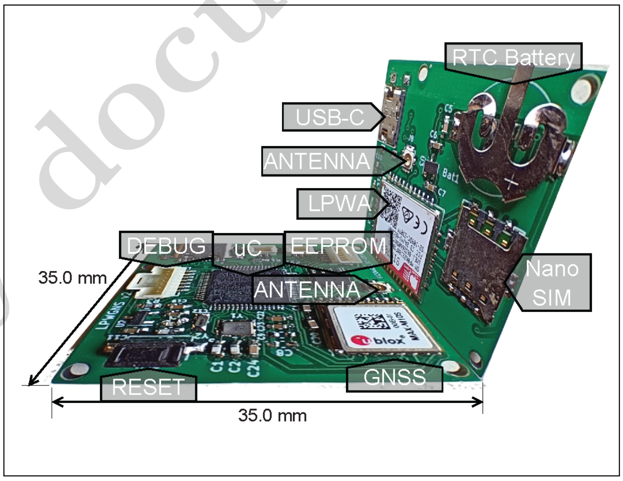

Figure 2: PCB of the noise measurement station.

Several optimizations have been implemented to reduce the power consumption of the station in order to make it self-powered via a solar cell and a vibration energy harvester.
These optimizations include:

- One-third octave band computation based on Power Spectral Density.
- Signal decimation for frequency bands below 250 Hz.
- Reduce the CPU clock down to 16 MHz.
- Measure the geolocation once every 16 s and use interpolated positions.
- Data compression and transmission once every 3 minutes.
- Use of low-power and sleep modes of the microcontroller and shut down modules while not needed.

Table 1: Component list and budget of the noise measurement station.

Component	Price (€)
Microcontroller STM32	9.46
MEMS microphone	6.60
GNSS module	20.88
NB-IoT module	13.64
EEPROM	1.29
16.384 MHz oscillator	0.639
32.768 kHz oscillator	0.639
USB-C connector	0.75
LDO 2.1 V	0.357
LDO 1.8 V	0.47
Battery, SIM, connectors, switch, LED...	30.00
TOTAL	84.73

All these optimizations reduce the power consumption of the noise measurement station by 80% and thus it can be self-powered by a solar panel and a vibration energy harvester [9].

3. Sampling routes

In order to compute the spatial and temporal sampling of the mobile measurement stations and to estimate the fleet size required for effective mobile noise mapping, a series of microtraffic simulations are carried out using SUMO (Simulation of Urban MObility) [10]. To support this analysis, the Accumulated Measurement Time (AMT) parameter is introduced, representing the cumulative duration of noise sampling within each street segment, that is the extent of data collected during one year of circulation (1500 effective working hours).

The simulations represent the city of Terrassa, which covers an area of 70 km^2 and has a population of around 230,000.

As a result, Fig. 3 shows the percentage of the total street segments of Terrassa that are sampled with an AMT exceeding a given threshold t within one year of measurement with 1, 2 and 3 mobile measurement stations. For instance, with only 1 station, 50% of the city is sampled with more than 20 minutes, whereas this percentage increases to >75% and >85% with 2 and 3 stations respectively. Fig. 3 also shows that with 3 measurement stations, in one year, 90% of the city is sampled with more than 15 minutes.

Fig. 4 shows the accumulated measurement times with one year and 1 measurement station in each street segment in Terrassa. According to Fig. 3, around 55% of all the street segments are sampled with accumulated measurement times longer than 15 minutes.

The resulting temporal sampling can be even further extended by adding the noise levels measured in adjacent street segments but at the cost of reducing the spatial resolution of the noise map. Therefore, care must be taken when selecting the street segments to aggregate [11]. The aggregation of adjacent street segments does not significantly improve the percentage of streets sampled with short AMT, but it does improve the percentage of streets sampled with large AMT.

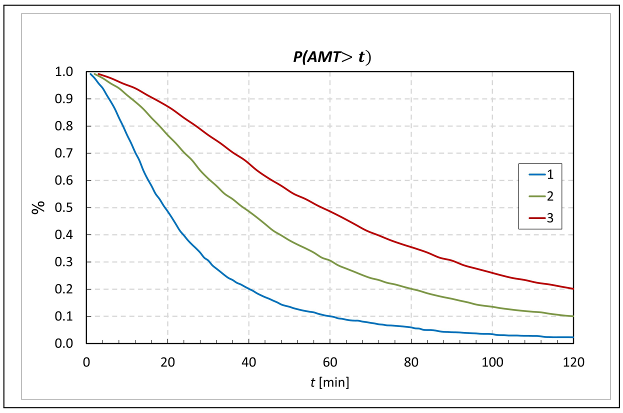

Figure 3: Percentage of the total street distance in Terrassa sampled with accumulated measurement times higher than t within one year with 1, 2 and 3 vehicles.

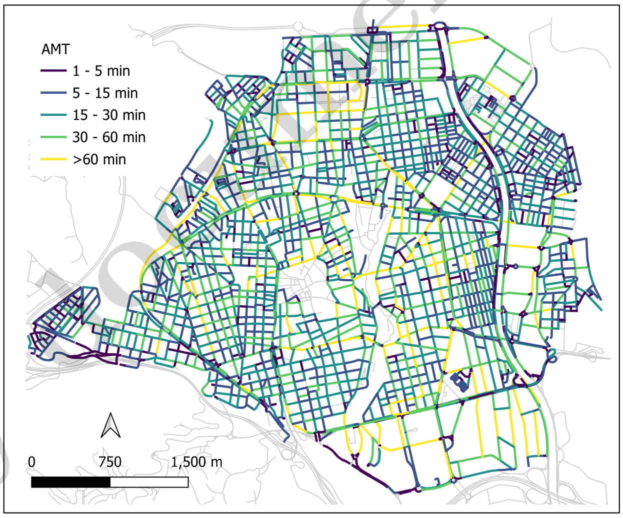

Figure 4: Accumulated measurement times in each street segment for a single mobile station during one year of circulation in the city of Terrassa.

For example, aggregating the two adjacent street segments to each street segment, increases the percentage of the city sampled with more than 15 minutes with only one measurement station from 61% to 89%, in contrast to the increase from 91% to 97% obtained for AMT > 5 minutes.

Finally, playing with the fleet size, i.e. the total number of measurement stations, and the aggregation distance, the traffic simulation allows computing the percentage of street segments sampled with an AMT greater than a given time during the desired operational period of the system, thus, adjusting the relationships of budget, time and accuracy needed to obtain a noise map.

4. Façade level estimation

Since the mobile stations mounted on vehicles take measurements of the noise levels at a position on the road and at approximately 1.5 m height, R_1, but noise maps, according to the European Direc-

tive 2002/49/EC, need to plot the noise levels at the façade and at 4 m height, R_2, a transfer function between these two points, as $\Delta L = R_1 - R_2$, is needed for different street configurations.
For this task, as shown in Fig. 5, a total of 998 R_1 points were manually deployed along the street network in a simulation of Terrassa, where R_2 positions were determined by projecting perpendicularly from the road centerline to the corresponding building façade and height. For each pair, the transfer function was defined as $\Delta L = R_1 - R_2$.

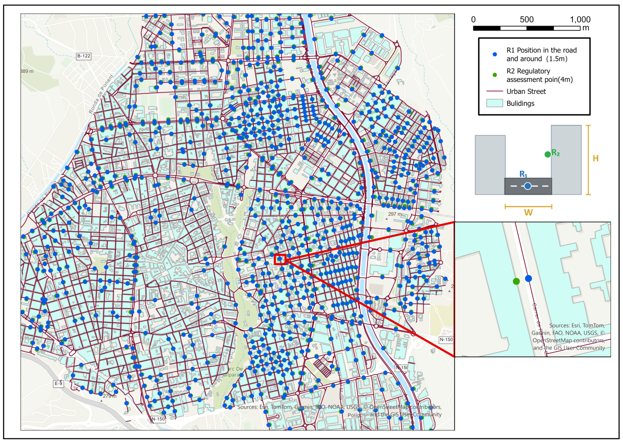

Figure 5: Spatial distribution of the receiver points across Terrassa. Blue points represent the fixed measurement positions R_1 located at the road center, while green points indicate the corresponding regulatory assessment points R_2 on the building façades. The zoomed-in inset illustrates the specific pairing method and the relative positioning of R_1 and R_2.

Noise simulations were performed using CadnaA software, employing CNOSSOS-EU as the calculation model. Both the ground and building façades were assigned concrete material with an absorption coefficient, α of 0.02, simulating a hard, reflective surface.
Based on the simulation results, 6 different regression models for ΔL were tested with different geometric parameters, such as the width of the street, W, the height of the buildings, H, and relationships between these parameters, such as the aspect ratio, H/W. Moreover, the shape of the street configuration was also taken into account separating:

- U-shape: Buildings on both sides, with a relatively symmetrical height distribution, $\Delta H \leq 50\%$.
- J-shape: Buildings on both sides, but with significant height asymmetry, $\Delta H > 50\%$.
- L-shape: Buildings on only one side, semi open space.

However, the final results show that the most important parameter for the transfer function is the street width, W, and that there are no big differences between street shapes. The resulting transfer function for all the street shapes is $\Delta L = 0.18W + 1.30$ with $R^2 = 0.871$ (Fig. 6).

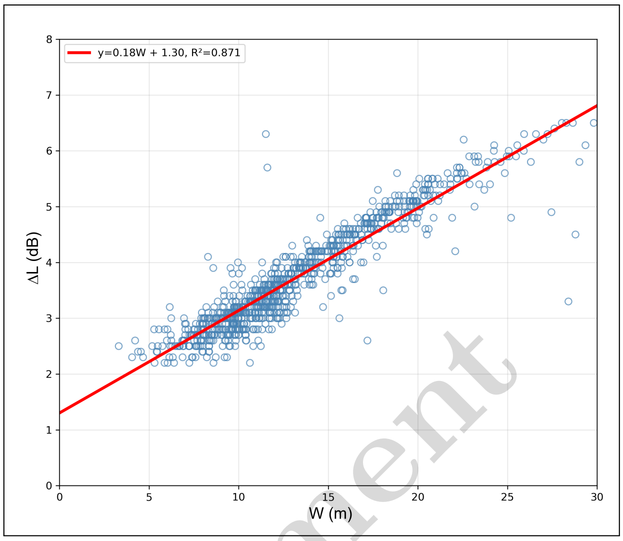

Figure 6: Fitting regression of the model $\Delta L = a \cdot W + b$ for all the 998 points simulated in Terrassa.

In addition, more detailed numerical simulations based on finite elements are being performed and also a measurement campaign is being carried out in order to test the transfer function computed via simulations.

5. Conclusions

The project MASANOM presents a comprehensive architecture for mobile urban noise monitoring, overcoming the limitations of traditional acoustic mapping through three key contributions:

- A novel autonomous noise measurement station that achieves up to 80% energy reduction using PSD processing, delta compression, and GNSS interpolation. It complies with IEC standards and can be continuously powered via solar panels and vibration energy harvesting.
- Micro-traffic simulations allow to establish the relationship between the number of measurement stations in circulation with the accumulated measurement times in each street segment, thus defining the total time needed to plot a noise map and its accuracy.
- A simple transfer function to estimate the noise levels at façade (R_2), to comply with the European Directive 2002/49/EC, from noise measurements at road-axis (R_1) using the street width (W) as the main predictor.

In synergy, these advancements enable a transition from static, five-year assessments to dynamic, high-resolution, low-cost and continuous urban noise mapping.

6. Acknowledgments

The authors would like to acknowledge the support of the MASANOM (Mobile Acoustic Sensor network for Automatic NOise Mapping) project funded by the State Research Agency under reference PID2022-141702OB-I00, within which this research was conducted.

References

[1] European Parliament and Council of the European Union, "Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise," *Official Journal of the European Communities*, vol. L 189, pp. 12–26, Jul. 2002.

[2] European Commission. Joint Research Centre. ICHP., *Common noise assessment methods in Europe (CNOSSOS-EU)*, en. LU: Publications Office, 2012. Accessed: Jun. 10, 2024.

[3] G. Bennett, E. A. King, J. Curn, V. Cahill, F. Bustamante, and H. J. Rice, "Environmental noise mapping using measurements in transit," *Proceedings of ISMA 2010 - International Conference on Noise and Vibration Engineering, including USD 2010*, pp. 1795–1809, 2010.

[4] E. A. King and H. J. Rice, "The development of a practical framework for strategic noise mapping," *Applied Acoustics*, vol. 70, no. 8, pp. 1116–1127, 2009.

[5] J. Gubbi, S. Marusic, A. S. Rao, Y. W. Law, and M. Palaniswami, "A pilot study of urban noise monitoring architecture using wireless sensor networks," in *2013 International Conference on Advances in Computing, Communications and Informatics (ICACCI)*, 2013, pp. 1047–1052.

[6] A. Can, L. Dekoninck, and D. Botteldooren, "Measurement network for urban noise assessment: Comparison of mobile measurements and spatial interpolation approaches," *Applied Acoustics*, vol. 83, pp. 32–39, 2014.

[7] International Electrotechnical Commission, "IEC 61260-1:2014 Electroacoustics - Octave-band and fractional-octave-band filters - Part 1: Specifications," International Electrotechnical Commission, Geneva, Switzerland, Standard, Mar. 2014.

[8] G. Quintero, A. Balastegui, and J. Romeu, "A low-cost noise measurement device for noise mapping based on mobile sampling," *Measurement*, vol. 148, p. 106 894, Dec. 2019.

[9] G. Quintero, A. Balastegui, and J. Romeu, "Autonomous mobile low-cost sensor node for high-resolution noise sampling in urban environments," *Measurement*, vol. 269, p. 120 720, 2026.

[10] "Eclipse SUMO - simulation of urban MObility," Eclipse SUMO - Simulation of Urban MObility. `https://eclipse.dev/sumo/`, Accessed: Feb. 24, 2026.

[11] G. Quintero, A. Balastegui, and J. Romeu, "Traffic noise assessment based on mobile measurements," *Environmental Impact Assessment Review*, vol. 86, 2021.