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# Mobile sampling to enhance data acquisition for noise mapping

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**ABSTRACT**

**Noise maps, whether they are based on simulation or in measurements, share the difficulty of data acquisition, since several input information is required to properly represent the temporal and spatial evolution of noise in the place under assessment. Therefore, mobile sampling could be a proper solution to enhance data acquisition, as it would increase considerably the spatiotemporal resolution of noise samples without compromising the accuracy and representativeness. In order to perform noise measurements in movement, the present research proposes a scheme of mobile sampling based on a low-cost georeferenced noise sensor mounted on a bicycle. To validate the application of the mobile sampling approach, several mobile and static measurements are taken, then an analysis between mobile and static sampling is performed.**

**Keywords:** Low-cost sensor, Noise mapping, Mobile sampling
**I-INCE Classification of Subject Number:** 72
(see http://i-ince.org/files/data/classification.pdf)

## 1. INTRODUCTION

To produce a noise map, whether it is based on measurements or based on simulations, requires high amount of input data to properly represent the acoustic environment of the place under assessment. Since the European Noise Directive [1] requires a report of the implementation of the directive to be presented every 5 years, which involves an update of the noise maps, makes the noise assessment a resources and time consuming task for local authorities.

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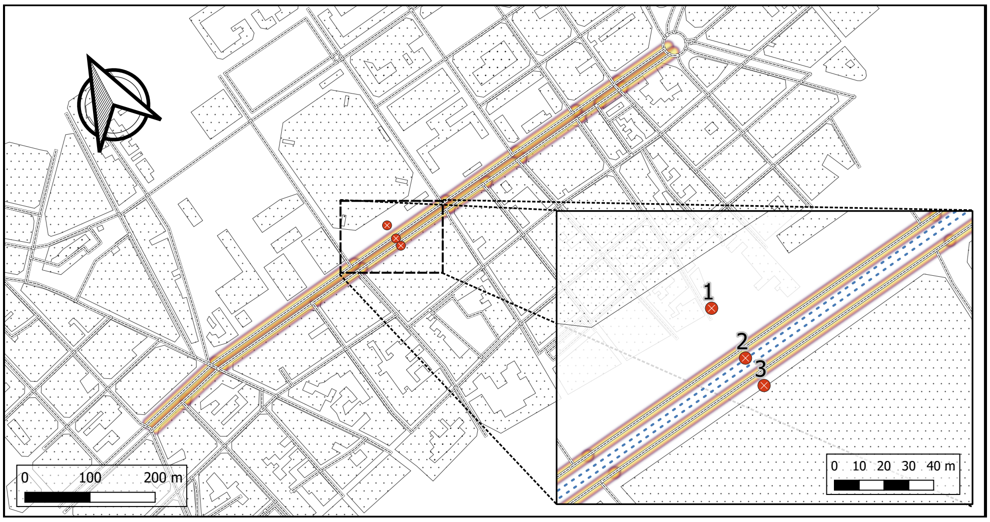



*Figure 1: Map of the place under study. The segment of the road under study is highlighted and the fixed measurement points are indicated as a circle: 1) Free field, 2) Center and 3) Facade.*

To develop a noise map based on measurements, it is required that a professional samples the noise levels on-site with certified equipment in many points [2–4], for periods that varies from minutes to hours [5–13]. Nowadays, different sampling approaches has been followed in order to optimize the sampling process. Sensor networks have emerged as an option to improve the time and space data granularity [14]. Furthermore, participatory sensing, has been shown to allow producing noise maps with enough accuracy as the standard ones [15–17]. Its main objective is to let to the citizens the sampling process mainly through dedicated equipment or their own mobile phones.

Recently, mobile monitoring has gained interest since it also increases spatio-temporal resolution but in a more controlled environment as the measurement would be performed by trained people. Taking mobile samples requires the data to be georeferenced [18, 19] and a proper vehicle to mount the noise sensor [19–21]. Other variables such as the microphone position, GPS accuracy, the noise contribution of the vehicle itself should also be taken into account [19].

The present research proposes taking mobile samples with a low-cost georeferenced noise sensor mounted on a bike. The measuring device consists in a microcontroller, a digital MEMS microphone, a Micro-SD and a GPS module. In order to test the accuracy of the mobile sampling, several mobile measurements are taken simultaneously to static ones (reference). Then, an analysis of mobile and fixed measurements is performed.

## 2. AREA UNDER STUDY

The area under study is the street Abat Marcet in the city of Terrassa, Catalunya, Spain, which is a two-ways road (3 lanes by each side) with a two-ways bicycle exclusive lane in the center. The total width of the street is approximately 33 meters including sidewalks (22 m only traffic lanes). The length of the segment of the road where the mobile samples are taken is around 1 km. Figure 1 shows the zone under study as well as the fixed sampling points position.

Five passes-by of each side of the road (10 rounds in total) are taken using one measurement equipment mounted in a bicycle, as shown in Figure 2. Special care is taken


*Figure 2: Bicycle with the measuring device mounted under the seat. The microphone is located at the top of a tube at an approximated height of 2 m.*

Table 1: List of materials and total price for a single prototype.

| ***Name*** | **Description** | **Price (€)** |
|---|---|---|
| ***STM32F411RE*** | Microcontroller with evaluation board | 11.09 |
| ***SPH0645LM4H-B*** | Digital MEMS microphone breakout board | 5.70 |
| ***GPS*** | GPS Module (single chip) and its matched antenna | 18.89 |
| ***MIC5504-3.3YM5-TR*** | LDO voltage regulator | 0.12 |
| ***Micro SD*** | 16 GB Micro SD memory | 11.91 |
| ***Connectors and case*** | Coin cell, AA battery holder, plastic case, microphone connectors, Micro SD connector, push button, leds, cables | 17.68 |
| **Total cost:** | | **65.39** |

about speed, road irregularities and self generated noise by the bike to avoid external noise sources. Furthermore, the speed of the bike is kept below 5 m/s to avoid applying corrections due to air flow. The microphone is also provided with a windshield for the same purpose.

Simultaneously to the mobile sampling, three static measurements are also taken, which are placed making a perpendicular cut to the street in order to measure the level in free field conditions, in the center of the street (close to the source) and in the facade (Points 1, 2 and 3 in Figure 1 respectively).

## 3. MEASUREMENT EQUIPMENT

In order to have more information to post-process the mobile measurements, the measuring device was designed to obtain the noise level at each third octave band from a frequency range between 50 Hz to 10 kHz. The main components and their price is shown in Table 1. Since the design of the measurement equipment is not the objective of this research, only a summary of the development and accuracy tests is presented.

### 3.1. Software implementation

The real time operative system (RTOS) of ARM mbed platform is used to handle the proper timing and task synchronization. To ensure that no data is lost, the sampling must be executed continuously. The other required tasks such as the signal processing, data storage and sample georeferencing, should also be carried on while the sampling task is running, but they are configured with less priority. The full process to compute the noise levels by the noise sensor is as follows:

(a) **Data sampling:** Is the task with the highest priority. Within this task, the samples are acquired from the MEMS microphone and stored in a temporary array of 4000 samples. Thus, for a sampling frequency of 32 kHz, the array is full every 125 ms which triggers the the signal processing task.

(b) **Signal processing:** The 125 ms samples are filtered for each third octave band frequency (50 Hz - 10 kHz). For frequencies below 2.5 kHz, a decimation filter (factor of 2) is applied to improve the filtering process and to reduce the required computations. Then, the sound pressure level is computed for each band. This task is repeated 8 times to achieve 1 second samples which triggers the georeferencing and data storage task.

(c) **Georeferencing and data storage:** The equivalent level of the 8 samples is computed for each third octave band (1 second $Leq_{fc}$). Then, the A-weighting coefficients are applied to all frequency bands and the 1 second $L_{Aeq}$ is computed. Finally, the data is georeferenced and the time-stamp is appended. The 1 second data is stored in the Micro-SD.

### 3.2. Calibration

Since the frequency response of the MEMS microphone is not flat for the required frequency range, a compensation for each Third Octave Band is applied. The calibration values are obtained from measurements performed inside a semi-anechoic chamber using 5 noise sensors and one Class 1 soundmeter (CESVA SC-310) as reference. The values were obtained from the average difference of each third octave band from the 5 noise sensors and the reference soundmeter for 4 different tests:

- Pink noise (70, 80 and 85 dB)
- White noise (75, 85 and 95 dB)
- IEC 61672-3 part 5.5 [22].
- IEC 61672-3 part 5.6 [22].

The calibration values and the standard deviation of the 5 noise sensors for the whole set of tests is shown in Figure 3.

## 4. MOBILE MEASUREMENTS ANALYSIS

### 4.1. GPS precision

An estimation of the accuracy of the GPS was computed. The perpendicular distance of the actual measurement location to the closest point of the bicycle exclusive lane was calculated, then, the average distance of all points was computed. Figure 4 shows how the distance was computed. The average position difference is 7.8 m with a standard deviation of 6.2 m. The average speed of the whole measurement time was also calculated obtaining a mean speed of 3.1 m/s.

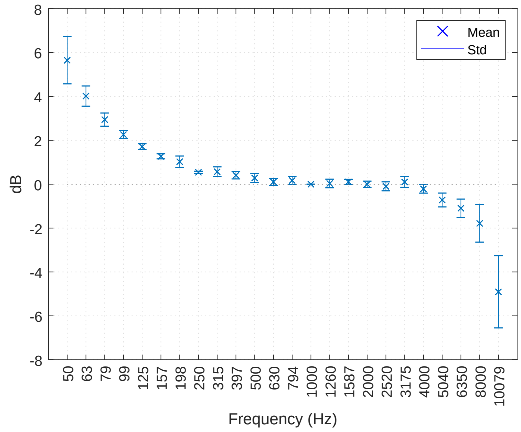



*Figure 3: Mean value and standard deviation of the calibration values of each third octave band (microphone frequency response) computed using 5 noise sensors.*

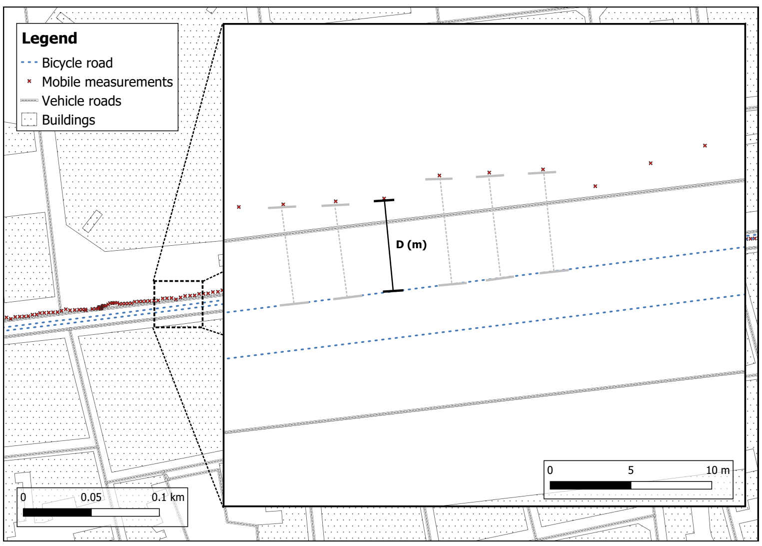
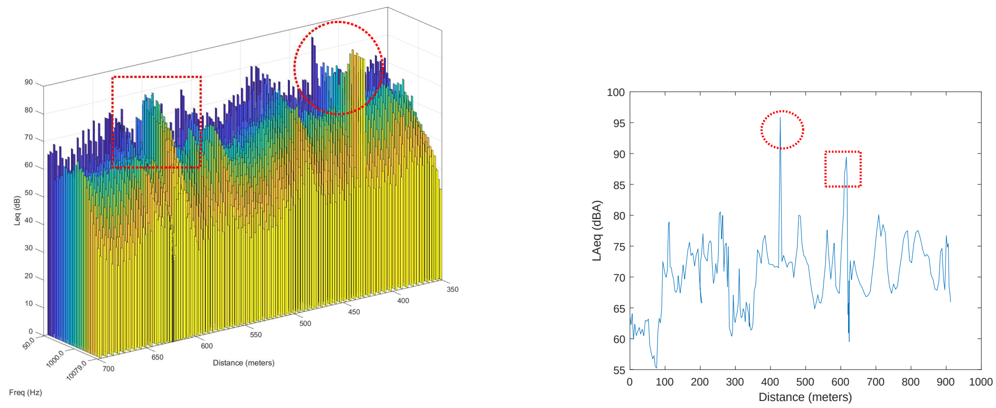



*Figure 4: Perpendicular distance of actual measurement to the closest point in the bicycle exclusive lane.*




(a) (b)

*Figure 5: (a) Bar plot of the equivalent level of each third octave band and (b) A-weighted equivalent noise level, both as a function of the distance traveled in Abat Marcet. A detected outlier probably due to an external factor is highlighted by circle. An increase in noise level, which is not considered outlier, probably to a very near position to a car is highlighted by a square.*

### 4.2. Outliers

The mobile measurements were analyzed in order to find possible outliers caused by external factors such as potholes, bumps, due to the bicycle itself or a failure in the noise sensor. The Figure 5 shows a representation of one outlier found in the $4^{th}$ round, it is highlighted by a red circle. Furthermore, an increase in the noise level which is not considered an outlier is also highlighted (red square).

After analyzing the measurement in a Geographical Information System (GIS), it was observed that the increase in the noise level (red square in Figure 5) was due to a semaphore. The bicycle stopped for a few seconds during the red light, time that the noise sensor was exposed to a greater amount of noise due to the proximity to the vehicles, and its further acceleration when the red light changed.

For the whole measurement time, a total of two outliers were found. It is seen that the outlier is characterized by an increment in the noise level in almost all the frequencies (specially the highest ones), which changes the frequency pattern of the sampled noise. A relation to a poor condition of traffic lanes or potholes could not be found since the outliers occurred in different places along the street. As the measurements were taken as a preliminary test in the early development of the noise sensor, the cause of the outlier due to a failure of the equipment is possible. Furthermore, since the noise sensor was directly attached to the bike, i.e. without extra protection for vibrations, a false contact could occur. Further research is required in order to reproduce and identify the outlier cause.

## 5. FIXED VERSUS MOBILE SAMPLING

A comparison between fixed and mobile samples was carried on following the procedure depicted in [21], where an analysis of mobile (walking person) and fixed measurements is performed. Thus, starting from the assertion that in terms of the spatial representativeness, the results obtained with the person walking are applicable to the bicycle measurement, the noise level difference was computed for the global $L_{eq}$, $L_{Aeq}$ and for each octave band between the fixed stations ($Leq_{Fix}$) and the mobile one ($Leq_{Mob}$).

The process to perform the noise level comparison is as follows:

1. **Time and space synchronization:** Obtain the closest point of the mobile measurement to the fixed station and shift in time the mobile signal (20 s window) until the maximum correlation coefficient is obtained.

2. **Spatial aggregation:** Aggregate the samples that are within a 35 m radius [21] from the center of the synchronized samples (fixed sensor as reference), to obtain the equivalent noise level (octave bands, $L_{eq}$ and $L_{Aeq}$).

3. **Fixed-Mobile noise levels:** Compute the noise level difference between the fixed noise sensors and the mobile one for the aggregated samples.

Figure 6 shows the comparison for each octave band, $L_{eq}$ and $L_{Aeq}$. As can be observed, the noise levels of the mobile measurement are always higher than the fixed one. It is a expected result since the bicycle is just next to the source. Furthermore, it can be observed that for Sub-figures 6a and 6b (free field and center respectively), all the frequencies have levels around ±2 dB taking the 1 kHz band as reference. In Sub-figure 6c (facade) a different pattern is observed. Compared to the free field conditions (6a), frequency bands under 250 Hz seem to have an increase in the noise level, which probably could be caused by the facade reflections as mentioned in [21]. The shape of the frequency bands above 250 Hz for both, free field and facade measurements, seems to have similar shape but with a higher noise level at the facade.

## 6. CONCLUSIONS

In the present research, a preliminary set of mobile measurements were analyzed. First, a low-cost georeferenced noise sensor was introduced. It was proposed to mount the device in a bicycle in order to diminish unwanted noise that would negatively affect the representativeness and accuracy of the samples.

Three fixed noise sensors were put perpendicular to the street in order to sample the noise in free field conditions, close to the source (center of the street) and in the facade. Then, 10 rounds (passes-by) were given along the street.

The analysis of the mobile samples suggest that an algorithm for outliers detection could be employed to remove unwanted sounds. Furthermore, special care should be taken when placing the device on the vehicle to reduce factors that could cause a failure of the noise sensor.

Finally, it was observed that the spectrum of the noise measurement at the facade is clearly different to the one measured with the mobile sensor, since an increase in the noise levels for the frequency bands under 250 Hz is observed. The possible reason are the reflections caused by the facade itself and the parked cars. Further measurements are required in order to confirm the observed pattern and to find the actual cause.

## 7. ACKNOWLEDGMENTS

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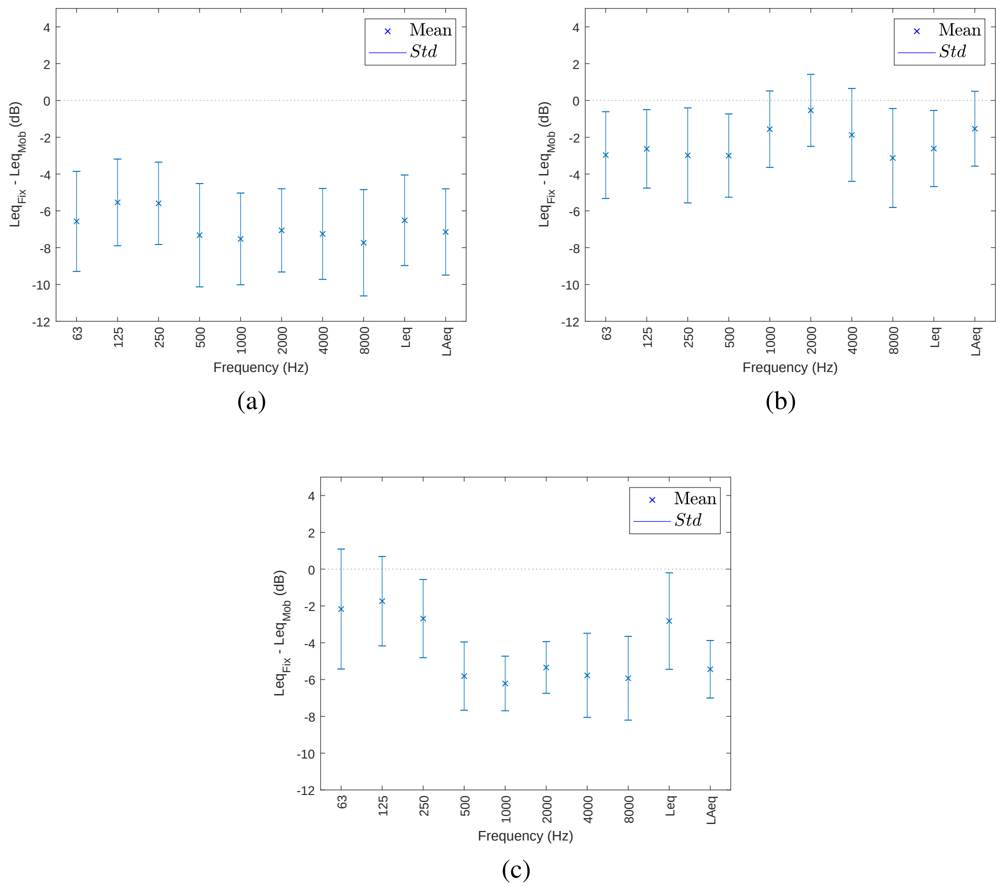


*Figure 6: Noise level difference between free field (a), central (b) and facade (c) fixed stations to the mobile one for each octave band (63 Hz - 8 kHz), $L_{eq}$ and $L_{Aeq}$.*

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