Applied Acoustics 83 (2014) 32–39

Contents lists available at ScienceDirect

Applied Acoustics

journal homepage: www.elsevier.com/locate/apacoust

Measurement network for urban noise assessment: Comparison of mobile measurements and spatial interpolation approaches

A. Can [a,*], L. Dekoninck [b], D. Botteldooren [b]

[a] LUNAM Université, IFSTTAR, AME-EASE, F-44341 Bouguenais, France
[b] Acoustics Group, Department of Information Technology, Ghent University, St. Pietersnieuwstraat 41, 9000 GENT, Belgium

ARTICLE INFO

Article history:
Received 31 May 2013
Received in revised form 19 December 2013
Accepted 17 March 2014
Available online 12 April 2014

Keywords:
Noise mapping
Mobile measurements
Spatial interpolation
Noise indicators
Measurement network optimization

ABSTRACT

This paper investigates the relevance of different interpolation techniques to improve the spatial resolution of urban noise maps, in complement to measurements achieved at fixed stations. Interpolation techniques based on mobile measurements are compared to usual spatial interpolations techniques, namely Inverse Distance Weighting and Kriging. The analyses rely on a measurement campaign, which consisted of nearly 8 h of geo-referenced mobile noise measurements performed at random moments of the day, conducted simultaneously with continuous measurements collected at five fixed stations located on the inner city of Gent, Belgium.

Firstly, a procedure is proposed to build a noise map with a high spatial resolution (one point every 5 m). The procedure relies on both mobile and fixed measurements: the mobile measurements are used to capture spatial variations on the network, and the measurements at fixed stations are used to capture the temporal variations. The map produced is then used as reference to compare the interpolation techniques based on a significantly more sparse measurement set.

The spatial interpolation techniques tested fail in predicting accurately the noise level variations within streets. The explanation given is that they do not offer a sufficient covering of the network, and assume spatial variations which are not coherent with traffic dynamics or street configurations. Inversely, mobile measurements cover the entire network. As a result, they allow a more accurate prediction of noise levels even if very short samples are used, provided that the procedure used to estimate noise levels includes a spatial aggregation, which aims at smoothing the high spatial variations inevitable with short samples. Moreover, mobile measurements can advantageously be used to optimize, through a Genetic Algorithm, the locations where to install fixed stations, promising an efficient noise monitoring at reduced operational costs.

1. Introduction

The strong recent urbanization and the increasing demand of city dwellers for a better quality of life have led to the development of policies towards sustainable cities. A consequence in regards to noise is the enactment of the European Noise Directive, which made mandatory strategic noise maps for cities with more than 100,000 habitants [1]. Those maps play an important informative role, pointing black points and quiet zones; this information has for example a significant impact on the property market [2]. They can also be a powerful tool for comparing the impact of different noise reduction strategies [3,4], provided that a special care is given during the traffic modelling step [5–7].

Although the directive leaves some liberty concerning the methods to produce noise maps, modelling based on traffic data collection and sound propagation calculation is the most widespread technique [8]. Noise contour maps with grid spacing of less than 10 m are then recommended in urban areas [8]. Spatial interpolation techniques can be used to determine noise levels with a greater resolution than the initial grid of results [9,10]. It has been shown however that this step can yield uncertainties, especially if maps are built based on wide initial grids [11].

Beyond their known advantages, modelling based on traffic data collection and sound propagation calculation has the disadvantage of needing some prior data collection and network acquisition steps that are long and costly. Moreover the estimation of noise levels within shielded streets requires time consuming sound propagation calculations [12,13]. Finally, some discrepancies can be observed between modelled maps, which mainly focus on road

* Corresponding author. Tel.: +33 2 40 84 58 53.
E-mail address: arnaud.can@ifsttar.fr (A. Can).

http://dx.doi.org/10.1016/j.apacoust.2014.03.012
0003-682X/

traffic noise, and measurements, which capture all kinds of noise sources [14].

Measurement is thus necessary to complement these models and calibrate noise maps [15–17]. Then measurement durations can be reduced by combining different sampling spans, either made of long-term (complete days [18,19]) or short-term (few minutes [20,21]) measurements. Spatial interpolations can afterwards be performed to assess noise levels between sensors; this last step also influences the accuracy of the noise maps obtained [22,23]. Another possibility offered by noise monitoring networks is their integration into wider heterogeneous monitoring networks, using their expected correlation with other traffic or pollutant parameters to reduce monitoring costs [24–26].

More advanced, the recent technological improvements, such as low-cost noise sensors [27] or mobile phones equipped with Global Positioning Systems (GPS) [28,29], open the possibility for dynamic noise monitoring relying directly on measurements. Measurements given by mobile phones can be accurate enough to fulfil the noise mapping requirements through participatory sensing [30]. Interestingly, the maps obtained could also help city dwellers to act directly on their exposure during soft mode displacements, by choosing low-exposure route options [31].

However, beyond the technological issues, some related statistical questions are arising, to guaranty a sufficient accuracy to those maps and optimize their spatial resolution-to-cost ratio. First elements of response can be found in [32,33], which showed how mobile measurements should be operated and processed, and in [34], which showed how temporary and fixed noise stations can be combined to estimate daily noise patterns.

The contribution of this paper is to test the benefits of combining measurements at fixed stations and interpolation techniques to estimate noise maps with a high spatial resolution. Interpolation techniques based on mobile measurements are compared to classical spatial interpolation techniques. Mobile data have been collected on a bicycle equipped with a GPS, in an area of Gent (Belgium). The 1-s evolution of sound pressure levels was measured. In addition, 5 monitoring fixed stations continuously measuring noise levels were placed at building facades. Interpolation techniques have been compared on their ability to estimate a selected set of noise indicators, the reference being the noise map built with the totality of the collected data.

Section 2 describes the experiment and the procedure followed to build the reference noise map. In Section 3, the potential of spatial interpolation techniques, namely the Inverse Distance Weighting (IDW) and the Kriging techniques, for improving the spatial resolution of noise maps, is evaluated. Results are compared in Section 4 with the estimations obtained with short term mobile measurements corrected with measurements collected at fixed stations. In Section 5, the possibility to rely on mobile measurements to optimize the location of fixed stations, thanks to a Genetic Algorithm, is evaluated. Finally, the conclusion lists some recommendations and the further investigations needed to improve measurement-based noise mapping.

2. Methodology

2.1. Site description and instrumentation

The experimentation consisted of a mobile measurements campaign, combined with simultaneous measurements at 5 fixed stations. The objective of this combination is to benefit from both measuring approaches: the mobile measurements can potentially capture the spatial noise variations along the network, while measurements at fixed stations can capture the temporal variations and determine overall noise levels. The procedure proposed is described in Section 2.2.

Measurements were conducted between 04/04/2011 and 18/05/2011, in a few neighbouring streets, covering 0.2 km^2 of the inner city of Gent, Belgium. Each mobile measurement consisted of a bicycle ride of approximately 20 min in the zone considered, performed at a random time of the day. The operator was equipped with a GPS and a microphone synchronized, collecting the 1s-evolution of positions and the 1 s A-weighted sound pressure levels $L_{\mathrm{Aeq,1s}}$, respectively. The Noise Level Meter used was a Type 1 Svantek 959®, protected by a waterproof windscreen, and calibrated on regular intervals using a Svantek SV 30 A acoustic calibrator. The Noise Level Meter was in a backpack, carried by the operator while cycling, and installed so that it was pointing upward, at the back of the bicyclist's head, less than 30 cm from the bicyclist's ears (see Fig. 1a). The bicycle speed was on average lower than 5 m/s as it was constrained by urban traffic. This guarantees that wind-induced noise did not perturb measurements, as environmental noise measurements are valid without any adjustment until this speed in the range of the noise levels measured according to standards [36]. Moreover, the bicycle was maintained with care, to limit the parasite noise generated by the bicycle itself, as recommended in [33]. Note that spectral evaluations could improve further operational use of mobile noise measurements as shown recently in [32], but this was out the scope of this paper.

A total amount of 7 h 51 min of data have been collected, resulting in a set of 28,260 elements of $\{t, x(t), y(t), L_{\mathrm{Aeq,1s}}(t)\}$ values. Note that the zone was unevenly covered by the experiment, as the rides followed random paths; the influence of this is discussed further in the paper.

Additionally, 5 microphones were placed at the facades of some buildings of the network, at heights between 3 and 5 m, measuring continuously the $L_{\mathrm{Aeq,1s}}$ evolution during the whole mobile measurements period. A detailed description of the noise measurement set up can be found in [27]. Two microphones were closely located near a crossing of the Doornzelestraat and the Sleepstraat, and one microphone was located in the middle of Sleepstraat; see their exact location in Fig. 2. Doornzelestraat and Sleepstraat are two busy 2-lane streets, with traffic flow rates that amount for light vehicles to about 4200 and 5800 Average Annual Daily Traffic for week days including holidays, respectively. Doornzelestraat is characterized by many bus passages and Sleepstraat is characterized by many tram passages in both directions. Two microphones were placed in calmer streets; one in the Bomastraat, where the traffic intensity is much lower, and one in Nieuwland, which is a one-way street mainly carrying local traffic and is the calmest street of the zone.

2.2. Reference noise map

A high spatial-resolution noise map has been built with the complete set of mobile data, combined with the data collected at the 5 fixed stations. It will be used as reference for testing the interpolation techniques. The procedure to build the reference map, validated in [31], is described below and contains three steps.

2.2.1. Mapping into a fixed grid

Positions given by the GPS are mapped into a fixed map of 662 points $p = \{x_p, y_p\}$, with $p = \{1\ldots662\}$, following the road network with a 5 m-resolution; see Fig. 1b. In practice, each of the 28,260 coordinates $\{x(t), y(t)\}$ collected on the bicycle is replaced by the coordinates of the closest point of the fixed map. Then, the 28,260 elements of $\{t, x(t), y(t), L_{\mathrm{Aeq,1s}}(t)\}$ values are subdivided into 662 samples s_p. Each sample s_p gathers the moments when the bicycle passed by p, that is the elements such as $\{x(t), y(t)\} = \{x_p, y_p\}$. It covers several pass-bys, each of a few seconds duration. For example, if the bicycle was constantly evolving at the speed