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A study of the accuracy of mobile technology for measuring urban noise pollution in large scale participatory sensing campaigns

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A B S T R A C T

The study reports on the relevancy and accuracy of using mobile phones in participatory noise pollution monitoring studies in an urban context. During one year, 60 participants used the same smartphone model to measure environmental noise at 28 different locations in Paris. All measurements were performed with the same calibrated application. The sound pressure level was recorded from the microphone every second during a 10-min period. The participants frequently measured the evolution of the sound level near two standard monitoring sound stations (in a square and near a boulevard), which enables the assessment of the accuracy and relevancy of collected acoustic measurements. The instantaneous A-weighting sound level, energy indicators such as $L_{A,eq}$, L_{A10}, L_{A50} or L_{A90} and event indicators such as the number of noise events exceeding a certain threshold L_α (NNEL $\geqslant L_\alpha$) were measured and compared with reference measurements. The results show that instantaneous sound levels measured with mobile phones correlate very well ($r > 0.9$, $p < 0.05$) with sound levels measured with a class 1 reference sound level meter with a root mean square error smaller than 3 dB(A). About 10% of the measurements for the boulevard location (respectively 20% for the square) were inaccurate ($r < 0.3$, $p < 0.05$). Nevertheless, mobile phone measurements are in agreement for the L_{A50} and the L_{A90} acoustic indicators with the fixed station (4-m high) measurements, with a median deviation smaller than 1.5 dB(A) for the boulevard (respectively 3 dB(A) for the square).

1. Introduction

Urban sound environment is an important element for the definition of the quality of life. Since 2002 and the European Directive 2002/49/EC, cities with >100,000 inhabitants must publish noise maps on a regular basis [1]. These maps show the L_{DEN} indicator and are used for policy support and to communicate with citizens about noise. Noise maps are currently generated out of a sparse measurement basis using complex processing steps including simulations. Increasing the number of measurement points is a good way to improve the quality and accuracy of noise maps [2,3]. However, a noise measurement network is expensive and complicated to upgrade.

On the other hand, the widespread use of small and powerful mobile devices enables a person-centric collection of environmental data giving rise to the idea of participatory sensing [4,5]. Thanks to the integrated sensors (such as microphone and GPS) and the availability of broadband internet access smartphones can be used as low cost sound level monitoring tools. In 2010, smartphones already surpassed personal computer sales evidencing that mobile devices were becoming fully integrated into everyday activities supplanting existing computers as internet devices. Half of the world's population now has a mobile subscription and the increase is very fast: from 3.6 billion in 2014 to 4.6 billion expected unique subscribers in 2020 [6].

In this context, one particularly interesting application in environmental acoustics is to collect participatory sound measurements. Thus, several government and research organizations have already commissioned noise pollution monitoring studies using mobile phones [7–10]. As a result, there has been considerable progress in technologies for participatory mobile sound measurements, giving rise to the development of several applications such as SoundCity [11], EarPhone [12], NoiseSPY [13], and NoiseTube [14]. Many research efforts have then focused on assessing

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the accuracy of the data gathered with these technologies inside and outside a laboratory [15–19]. However, it is also crucial to study and compare the results obtained during an entire large-scale participatory sensing field campaign with reference measuring methods such as noise-monitoring station measurements.

This paper studies the relevance and accuracy of mobile phones for measuring urban noise pollution in a large-scale participatory sensing campaign. In particular, the noise mapping campaign, organized in the context of the Cart-ASUR project (French acronym for: Cartographic representation of the quality of the urban sound environments) in Paris for a year is analyzed. The goal was to develop a cartographic indicator of urban sound quality, in terms of a variety of perceptive data together with the evolution of the sound level [20,21]. In order to evaluate the relevance of the mobile sound measurements, noise measurements were taken using both mobile phone technology and nearby sound monitoring stations. Instantaneous A-weighting sound level, energy indicators such as $L_{A,eq}$, L_{A10}, L_{A50} or L_{A90} and event indicators such as the number of noise events exceeding a certain threshold L_α (NNEL $\geqslant L_\alpha$) could then be compared with a reference measurement method of urban environmental noise.

The structure of this paper is as follows: First, an overview of the technical tools is presented (mobile phones, and application) and the procedure for correction of systematic errors by way of laboratory calibration. In Section 3, two 10-min smartphone measurement sessions are compared with a standardized sound level meter and with a 4-m high monitoring station at two locations. Then, an all-year measurements comparison with the noise-monitoring station is presented (n = 59). To conclude, the validity and accuracy of using mobile phones in a participatory noise measurement campaign is discussed in Section 4, where a general perspective on potential improvements is proposed.

2. Experimental setup

The technical setup and calibration methodology is described in this section. After this phase of calibration and application development, a sound measurement campaign was performed in Paris between September 2013 and September 2014. During one year, a total of 3409 assessments were carried out with 60 mobile phones at 28 selected locations in Paris during up to five homogenous periods (day, evening, night, summer, winter). Each situation (one location at one homogenous period) was assessed by about 20 people. A specific mobile phone model was given to the 60 participants and internet and communication subscription was offered for a year in order to control the experimental procedure to a required extent. Before each perceptive assessment, sound pressure levels were recorded each second during a 10-min period.

2.1. Noise measurement software

A specific mobile phone application was developed, based on the NoiseTube open-source application [14] (see Fig. 1). With the NoiseTube application, it is possible to record the sound pressure level every second and to calculate the equivalent sound level in dB(A). In addition to noise levels, the new Cart_ASUR application collects perceptive data in specific places (parks, squares, thoroughfares, streets, schools, markets, pedestrian streets, etc.). The application has been developed to respect to a great extent the European measurements standards (A-filtering, direct read-out of sound levels in dB(A), computation of $L_{A,eq}$ over arbitrary time intervals, calibration, spherical sensitivity and wind protection) [22]. The sound pressure level is recorded for each second from the mobile phone's microphone during a 10-min period. It has been stated in earlier research [23] that this duration is long enough to characterize the acoustic environment of an urban situation. From these measurements 20 acoustic indicators, often used in environmental acoustics, are calculated as in [24]. In this study, the accuracy of the following metrics is assessed: L_{A1s}, $L_{Aeq,10min}$, L_{Ax} *for* x = 5, 10, 50, 90, 95, σ and L_{A10}–L_{A90} as well as the event indicators, Number of Noise Event, $NNE_{L>y}$ and $\mathrm{NNE}_{L>LAeq,10min+z}$, and Mask Index, $MI_{L>y}$ and $MI_{L>LAeq,10min+z}$ with y = 70, 75 and 80 dB(A) and z = 10 and 15 dB(A). Consequently all the measurements were stored in real-time on servers, accessible via internet. Also, measurement quality and experiment progress could be checked during the entire campaign. If repetitive occurrence of erroneous results were observed, the concerned user was contacted for verification.

2.2. Smartphone calibration methodology

The mobile phone calibration methodology was realized by BrusSense Team of Vrije Universiteit Brussel (VUB) respecting the principles stated in [16,25]:

(1) The calibration was only carried out on the global dB(A), taking a pragmatic stance that sound levels have the most important impact in urban environment and this unit is the one used in most of noise environmental regulations. However it was also considered that in the frequency and the level ranges where urban sounds are dominant, the mobile phone behaves generally linearly (as shown in Fig. 2 for the mobile phone chosen in this study).
(2) As different mobile phone models show different behavior, even in the same brand, the calibration parameters must be calculated for each model.
(3) The calibration realized on one mobile phone model is approximately suitable for all the phones of the same model, even if the history of utilization from the phones differs.

White noise was used as a reference source to perform the calibration. This was generated in a anechoic chamber from 35 to 100 dB(A) by 5 dB(A) steps. All the phones were tested at the same time, with the microphone facing towards the loudspeaker (at 1 m distance) as well as the referenced microphone. The directivity influence has not been evaluated. Each step was maintained for at least 30 s in order to stabilize the noise level measurement. Calibration was performed by a comparative study between the assessed mobile phones and a reference class 1 sound level meter model CEL-500.

2.3. Mobile phone model choice

At the outset, a bench test was conducted in order to choose the mobile phone model to use during the campaign. A relevant factor for choosing the model was the fact that the mobile phones were going to be used for measuring noise in an urban environment. Two mobile phone models were sent to the laboratory in response to a public tender with demanded specifications, such as price and also microphone sensitivity, internal memory, cut off frequencies, battery autonomy and Android operating system. The measurements were done with the Noise Tube Application. Results showed that the HTC One X was best suited for this study as it showed a good sensitivity in the 35–100 dB(A) range. The tested Samsung Galaxy S3 was more sensitive at low sound levels but showed a low sensitivity around 90 dB(A), which could be problematic in an urban environment context (see Table 1).

After having selected the HTC One X model, its frequency response was then measured and compared to a reference G.R.A.S. MCE 212 class 1 microphone in a small semi-anechoic chamber and with a Genelec 1031A loudspeaker. Fig. 2 shows that the