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Probabilistic modeling framework for multisource sound mapping

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ABSTRACT

The process of modeling noise maps is now well defined: long-term aggregated indicators are calculated based on a collection or estimation of road, air and rail traffic variables. This framework however disregards the sound levels variations, and hence prevents the production of statistical or emergence indicators, and does not allow for the study of competition between typical urban sound sources that can improve the characterization of urban sound environments. A modeling framework in four steps is proposed to answer these issues: (i) a spatial distribution of the potential sound source of interest, (ii) the calculation of a sound propagation matrix, (iii) the stochastic activation of a sound sources ratio for n iterations of the sound map, and (iv) the calculation of specific sound indicators. The stochastic approach proposed in this study enables the estimation of the temporal sound distribution per sound source. It permits in particular to deduce source-oriented indicators such as the percentage of the time when a given sound source emerges from an urban sound mixture. An example of application of this framework is exposed for a district in the city of Nantes, France. It shows the interest of such approaches, in particular for soundscape and urban sound environment studies.

1. Introduction

The representation of urban sound environments through noise maps became standard since the enactment of the European Noise Directive 2002/49/EC [1]. The modeling framework to generate noise maps is now well established: long-term aggregated indicators are calculated based on a collection or estimation of road, air and rail traffic variables, followed by sound emission and propagation calculations [2]. This framework however disregards the sound levels variations, and hence prevents the production of statistical or emergence indicators that improve the characterization of urban sound environments [3–5].

In addition, limiting sound maps to traffic sources truncates the reality. A wider range of sound sources, including natural sounds, intervenes when people are asked to describe urban sound environments and evaluate their quality [6–8]. Some models link perceptual variables, especially soundscape pleasantness, to the time of presence of typical urban sound sources such as birds or voices and experience shows that natural sounds are often perceived as impacting positively the soundscape pleasantness [9–11]. The relative impact of sound sources is however more complex: the positive effect of voices can be for instance annihilated when voices are too numerous or misfit the context [12]. Interactions between sources are also of importance, as shown in [13] between road traffic and industrial noise, or between natural sound sources and road traffic noise [14–17].

In consequence, sound mapping recently moved towards multi-sources approaches [18,19]. In [20], the presence of sources, categorized into traffic, water, human and bird sounds, is evaluated perceptually at sampled locations and interpolated to create sources-oriented noise maps. A modeling approach is followed in [21]: specific noise maps are built for road traffic, fountains, and birds, which are placed by default at trees locations. In recent years, acoustic emission and propagation models have been integrated directly into Geographic Information Systems (GIS) [22,23] and sources-oriented noise maps can benefit from this environment [24]. Lavandier et al. related the perceived loudness of the global sound environment and perceived presence time ratio of some sound sources of interest, namely traffic, voices and birds, to geographical indicators [25]. If these first researches prove the feasibility and interest of producing source-oriented noise maps, they need further investigations to better consider the sound sources localization and temporal activities, as well as their specific levels and spectral contents. For supporting such researches, it will be helpful that all the source-oriented noise maps are produced using independent emission models for each type of sound source and sharing an identic acoustic propagation model. So that, the new advances would not affect other sound sources emission model and the propagation modeling framework. In addition, the described mapping experiences were based on static approaches that hinder the masking that occurs between sound sources. Indeed, the respective temporal variations of sources are known to strongly impact the fact of hearing or not a sound source within an urban sound mixture, through for instance auditory attention processes [26].

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We propose a probabilistic modeling framework for producing source-oriented sound maps within an open-source GIS, which shares the same structure, described in Section 2, whatever the sound source is. The model is illustrated for the production of traffic, fountains, voices and birds sound maps in Section 3. As shown in Section 4, the original probabilistic approach makes it possible to investigate the competition between sound sources, that is to say the probability that a sound source, or a group of sound sources, will be louder than other ones.

2. Method

2.1. Modeling framework

2.1.1. General presentation

The modeling consists of producing source-oriented sound maps. Our approach is stochastics: a set of *n x k* sound maps is created, corresponding to *n* representations of the possible instantaneous sound environment for each of the *k* considered sound source. Each sound map i_k can be seen as the photography at one instant of the possible encountered equivalent 1-s sound environment for the contribution of a given sound source. Statistics are done on a sufficient representative number of maps to characterize the sound environment where the model input parameters are stable (*e.g.* constant bird's density during the study period and area). The objective is thus to account for the 1-s time variability of the sound environment to compute original sound environment indicators. The time evolution of sound environments, that is the coherence between two consecutive iterations *i*, is not a target output of the modeling. We follow the same modeling framework in four steps whatever the sound source is.

Although the modeling framework contains the same four steps whatever the sound source is, the content of each step differs from one sound source to the other, based on knowledge on its characteristics. In terms of modeling, some sound sources are very well documented in terms of both sound emission and spatial repartition, while other ones require specific modeling. The interest of the approach lies here in the fact that: (i) new sound sources can easily be implemented following the same modeling approach, (ii) each step can be improved through further research without compromising the rest of the modeling chain.

2.1.2. Step 1

The spatial repartition of the potential sound sources (humans, birds, cars, etc.) is defined. To limit the calculation time, the spatial repartition correlates to the density of the sound sources within each zone for a given time period. For instance, in the example illustrated in Fig. 1 birds are located within the park where they are more prone to be found.

2.1.3. Step 2

The matrix of attenuation per octave band (63–8000 Hz), between each couple receivers and potential sound source, is calculated (see Fig. 2). We consider that for the stable considered period of time, the acoustic propagation remains unchanged.

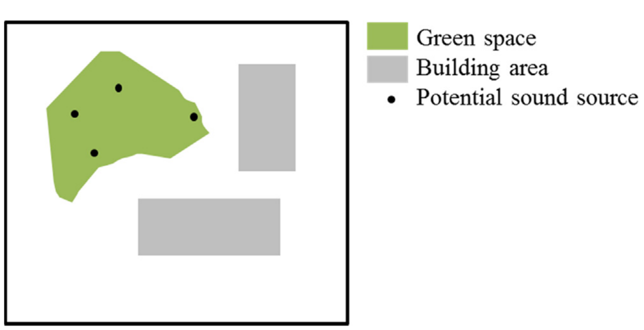

Fig. 1. Graphical resume of Step 1. The potential sound sources, here birds, are placed in the park.

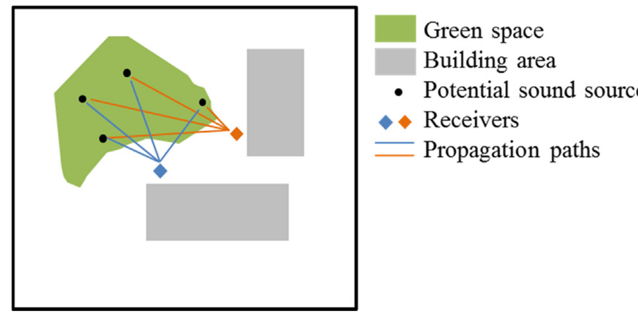

Fig. 2. Graphical resume of Step 2. All the propagation paths are calculated between the couples sound sources/receivers.

2.1.4. Step 3

As presented in Fig. 3, a set of *n* sound maps is created for each sound source *k*. Each sound map is calculated by activating randomly a proportion of the potential sound sources with respect to knowledge on the activity of the sound source objects. For instance if it is assumed that 30% of the present humans are speaking during the same second, only 30% of the located humans randomly selected on the map are activated for a sound map *i*.

A 1-s equivalent sound power level and spectrum is assigned to each activated sound source, based on knowledge on the sound source: 1-s variability in sound power levels, sound spectrum, prosody for the voices, etc. Each sound map *i* is calculated by summing the contribution, at each receiver, of each sound source activated at *i*. The individual contribution of each sound source is the sum between the sound power level and the sound propagation attenuation calculated at step 2.

Note again that the activated sound sources vary at each iteration, but that the attenuation matrix is only calculated once, hence strongly limiting the computation time.

2.1.5. Step 4

Sound level indicators are calculated at each receiver based on the sound maps. The original sound indicators can be statistical levels for each modeled sound sources (L_{10}, L_{50} and L_{90}, which stand as the sound level exceeded 10, 50 and 90% of the time, respectively). But also, it can be the proportion of the combinations between the *n x k* sound maps computed for each sound source where the sound level of a defined sound source is superior to the other ones. For instance, for x% of the *n x k* computed sound maps the birds sound level is superior to the sound level of the road traffic. A graphical summary is shown in Fig. 4.

2.2. Software environment and sound propagation modeling

All the modeling steps are implemented within the open-source GIS software OrbisGis.[1] OrbisGIS allows researchers to share their results and build a common platform to analyze sustainable urban development. OrbisGis is compatible with the use of Open Street Map[2] (OSM) databases (i.e., buildings, roads, etc.) and facilitates the representation of the produced sound maps. In this study, all the geographic information has been imported from the Geofabrik[3] portal except the traffic data which own to the Nantes city council.

The sound propagation done during the step 2 presented above utilizes the free and open-source Noisemodelling plugin,[4] which has

[1] http://orbisgis.org.
[2] https://www.openstreetmap.org.
[3] http://download.geofabrik.de.
[4] http://noise-planet.org/en/noisemodelling.html.