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Research Paper

Participatory soundscape sensing

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ABSTRACT

Soundscape research offers new ways to explore the acoustic environment and potentially address challenges. A comprehensive understanding of soundscape characteristics and quality requires efficient data collection and analysis methods. This paper describes Participatory Soundscape Sensing (PSS), a worldwide soundscape investigation and evaluation project. We describe the calibration method for sound pressure levels (SPL) measured by mobile phone, analyze the PSS's data temporal-spatial distribution characteristics, and discuss the impact of the participants' age and gender on the data quality. Furthermore, we analyze the sound comfort level relationships with each class of land use, sound sources, subjective evaluation, sound level, sound harmoniousness, gender, and age using over a year of shared data. The results suggest that PSS has distinct advantages in enhancing the amount and coverage of soundscape data. The PSS data distribution is closely related to the temporal pattern of the human work-rest schedule, population density, and the level of cyber-infrastructure. Adults (19–40 years old) are higher-quality data providers, and women exhibit better performance with respect to data integrity than men. Increasing the proportion of natural source sounds and reducing the proportion of human-made sources of sound is expected to enhance the sound comfort level. A higher proportion of sound harmoniousness leads to higher sound comfort, and the higher proportion of subjective evaluation sound level does not lead to decreased sound comfort. We suggest that the crowdsourcing data with participatory sensing will provide a new perspective in soundscape investigation, evaluation, and planning.

1. Introduction

Soundscape can be defined as the acoustic environment perceived, experienced, and/or understood by a person or people in a given context (ISO 12913-1, 2014), which places emphasis on the perception, evaluation, and experience of the listeners. The urban soundscape approach considers the acoustic environment as a "resource" (Brown, 2012) with the goal of improving urban sound quality via design and planning. The main topics of the urban soundscape include sound source identification (Jeon & Hong, 2015), spatial-temporal variation (Hong & Jeon, 2017; Liu, Kang, Luo, Behm, & Coppack, 2013), indicators selection (Aletta, Kang, & Axelsson, 2016), sound evaluation (Yang & Kang, 2005; Zhang, Zhang, Liu, & Kang, 2016), and soundscape design (Chung, To, & Schulte-Fortkamp, 2016). Soundscape research methods, including pen and paper questionnaires, interviews, sound walks, and replaying of sound records in the lab, have been used to collect data, such as sound sources, sound pressure levels, location information, individual feelings, and demographic factors, among others (He & Pang, 2016; Kang, 2014; Liu, Kang, Behm, & Luo, 2014), and most of these factors have significant costs and time investment. Lab tests mean that volunteers cannot feel the real soundscape directly and, moreover, a long test can easily tire the participants. As a result, current research projects are primarily conducted at a small scale, such as in a park or green space, which leads to results that are difficult to apply on a large scale. Because soundscape design includes multi-party participation and discussion, reasonable soundscape design requires additional participants (He & Pang, 2016).

Participatory sensing (PS) is the process through which individuals and communities use the capabilities of mobile devices and cloud services to collect, analyze, and contribute sensory information (Burke et al., 2006; Estrin et al., 2010). Using the concept of PS, sound-recording and noise-monitoring mobile applications and online web survey software have been reported. Noteworthy is that some mobile phones' accuracy for measuring noise pollution has been tested (Aumond et al., 2017), but few of them may be appropriate for noise measurement (Kardous & Shaw, 2014). The soundscape quality-related information, including such factors as sound pressure level (SPL), sound frequency, land use, or subjective evaluation, cannot be completely

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recorded (Becker et al., 2013; Cordeiro, Barbosa, & Afonso, 2013; Craig, Moore, & Knox, 2017; Drosatos, Efraimidis, Athanasiadis, Stevens, & Hondt, 2014; Hedfors, 2013; Yelmi, Kuscu, & Yantac, 2016). Additionally, the quality and characteristics of these crowdsourced data lack detailed descriptions or discussion.

In this paper, we propose Participatory Soundscape Sensing (PSS), which is an ongoing worldwide soundscape investigation and evaluation project that engages the public in participatory sensing. We describe the PSS tools and the calibration method of SPL as measured by mobile phones. We analyze the temporal-spatial distribution characteristics of the PSS data; discuss the impact of the participants' age and gender on the quality of data, including length of measurement time and soundscape records integrity; and analyze the sound comfort level relationships with each class of land use, sound sources, subjective evaluation sound level, sound harmoniousness, gender, and age.

2. Methodology

2.1. PSS tools development

The PSS tools include SPL Meter and PSS Server. SPL Meter (which can be downloaded at http://www.citi-sense.cn/download) is a soundscape data investigation and analysis software package that can be installed on both Android and iOS operating systems. PSS Server runs on a cloud server and can analyze and visualize soundscape data online from around the world (http://pss.citi-sense.cn).

Fig. 1 shows the logical architecture of SPL Meter contains four main components, including SPL calculation, location and sound source identification, demographic information and time collection, and results storage and sharing.

2.1.1. SPL calculation

A continuous signal can be adequately sampled only if it contains frequency components greater than one-half of the sampling rate (Smith, 1999). The average human ear senses tones resulting from sound oscillation at frequencies between 20 and 20,000 Hertz (Hz), and the most sensitive frequencies span the range of 2000–5000 Hz. SPL Meter receives 16-bit PCM (pulse-code modulation is a digital representation of an analogue signal) at a speed of 44,100 Hz from its microphone. SPL Meter extracts the amplitude and frequency from the sampled signal using the Fast Fourier Transformation (FFT). For the purpose of this application, the calculation method of FFT comes from the ddf.minim.analysis package and the block size was set as 2048 in FFT. The human ear does not respond to these frequencies equally well and is less sensitive to extreme high and low frequencies; therefore, an A-weighted SPL, which is modified by the A-weighting filter, is commonly used in noise dose measurement at work. The A-weighted equivalent continuous sound level (L_{Aeq}), maximum sound level (mL_{pa}) and its corresponding frequency (mF), the sound level exceeded for 10% of the time of the measurement duration (L_{10}), the sound level exceeded for 50% of the time of the measurement duration (L_{50}), and the sound level exceeded for 90% of the time of the measurement duration (L_{90}) can be calculated using A-weighted SPL. The calculation results are shown on the main screen of the SPL Meter by numeric representation or as a graph.

2.1.2. Location and sound source identification

Differences in land use and sound sources can affect the perception of the soundscape (Kang, 2007). The information for land use and sound sources can be identified by the participants using a list in the evaluation interface of the SPL Meter app. The latest list of land use and sound sources is supplied when SPL Meter connects to PSS Server each time it starts. Each item of the land use and sound sources has a unique code. The lists are updated if new items (sound source or land use information) are added to the lists in PSS server. The location coordinates are collected using the mobile phone's high-accuracy location service (GPS, WLAN, or mobile networks).

2.1.3. Soundscape evaluation

The subjective evaluation of sound levels, sound comfort levels, and sound harmoniousness levels, which are widely used in soundscape evaluation (Aspuru, García, Herranz, & Santander, 2016; Kang, 2007), can also be applied in SPL Meter, where each is divided into five linear scales that were standardized in noise surveys (Fields et al., 2001). The level of harmonization between aural and visual perception has been defined as sound harmoniousness level in this study. Information related to the gender and age of the participants can also be collected if the user is willing to supply them. The local time, time zone, and UTC are obtained when SPL Meter is used to measure and evaluate the soundscape.

The state of the earphone is necessary to judge whether the internal or external microphone is used. Other hardware and software variations

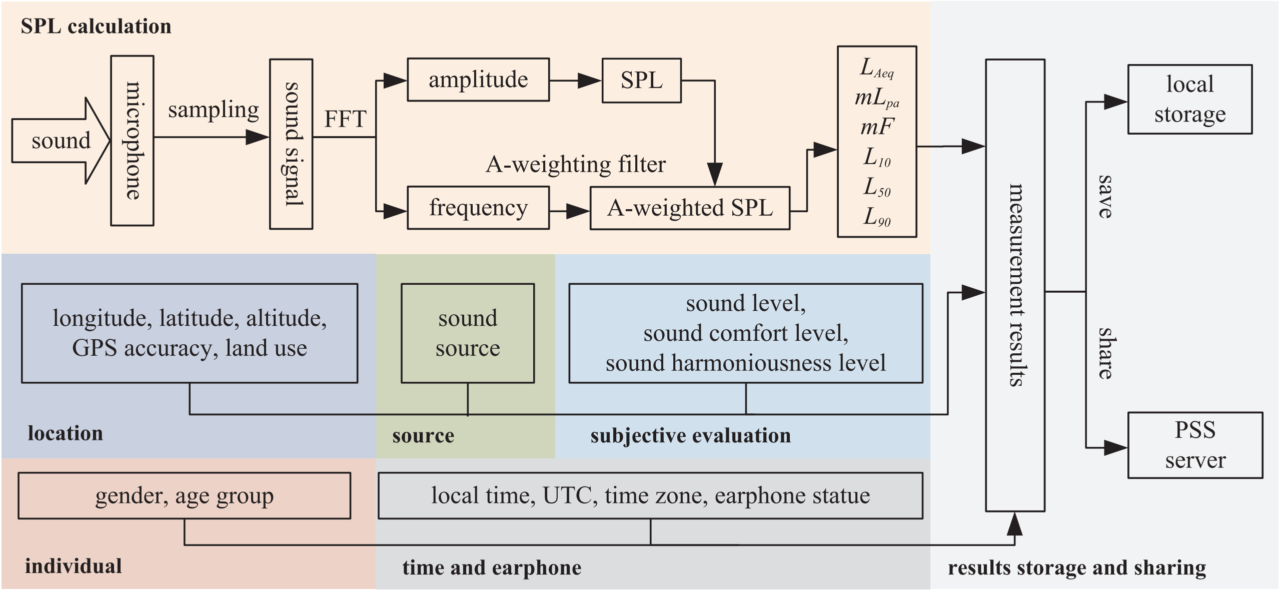

Fig. 1. Logical architecture for SPL Meter.