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The implementation of low-cost urban acoustic monitoring devices

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ABSTRACT

The urban sound environment of New York City (NYC) can be, amongst other things: loud, intrusive, exciting and dynamic. As indicated by the large majority of noise complaints registered with the NYC 311 information/complaints line, the urban sound environment has a profound effect on the quality of life of the city's inhabitants. To monitor and ultimately understand these sonic environments, a process of long-term acoustic measurement and analysis is required. The traditional method of environmental acoustic monitoring utilizes short term measurement periods using expensive equipment, setup and operated by experienced and costly personnel. In this paper a different approach is proposed to this application which implements a smart, low-cost, static, acoustic sensing device based around consumer hardware. These devices can be deployed in numerous and varied urban locations for long periods of time, allowing for the collection of longitudinal urban acoustic data. The varied environmental conditions of urban settings make for a challenge in gathering calibrated sound pressure level data for prospective stakeholders. This paper details the sensors' design, development and potential future applications, with a focus on the calibration of the devices' Microelectromechanical systems (MEMS) microphone in order to generate reliable decibel levels at the type/class 2 level.

1. Introduction

Noise pollution is an increasing threat to the well-being and public health of city inhabitants [1]. It has been estimated that around 90% of New York City (NYC) residents are exposed to noise levels exceeding the Environmental Protection Agencies (EPA) guidelines on levels considered harmful to people [2]. The complexity of sound propagation in urban settings and the lack of an accurate representation of the distribution of the sources of this noise have led to an insufficient understanding of the urban sound environment. While a number of past studies have focused on specific contexts and effects of urban noise [3], no comprehensive city-wide study has been undertaken that can provide a validated model for studying urban sound in order to develop long-lasting interventions at the operational or policy level.

To monitor and ultimately foster a greater understanding of urban sound, an initial network of low-cost acoustic sensing devices [4] were designed and implemented to capture long-term audio and objective acoustic measurements from strategic urban locations using wireless communication strategies. These prototype sensing devices currently incorporate a quad-core Android based mini PC with Wi-Fi capabilities, and a Microelectromechanical systems (MEMS) microphone. The initial goal is to develop a comprehensive cyber-physical system that provides the capability of capturing, analyzing and wirelessly streaming environmental audio data, along with its associated acoustic features and metadata. This will provide a low-cost and scalable solution to large scale calibrated acoustic monitoring, and a richer representation of acoustic environments that can empower a deeper, more nuanced understanding of urban sound based on the identification of sources and their characteristics across space and time. As part of this goal, work is ongoing to equip the sensors with state-of-the-art machine listening capabilities, briefly discussed in Section 9.3, such as automatic sound source identification through the development of novel algorithms. This approach aims to enable the continuous monitoring and ultimately the understanding of these urban sound environments.

1.1. New York City noise

In 2014 the NYC 311 information/complaints line,[1] received 145,252 complaints about noise, up 34% from 2013. As of August 2015, 105,063 noise complaints have already been registered [5]. NYC has tried to regulate sources of noise since the 1930s and in

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[1] http://www1.nyc.gov/311/index.page.

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1972 it became the first city in the U.S. to enact a noise code [6,7]. As a result of significant public pressure, a revised noise code went into effect in 2007 [8]. This award-winning code, containing 84 enforceable noise violations, is widely-considered to be an example for other cities to follow [9]. However, NYC lacks the resources to effectively and systematically monitor noise pollution, enforce its mitigation and validate the effectiveness of such action. Generally, the Noise Code is complaint driven. The NYC Department of Environmental Protection (DEP) inspectors are dispatched to the location of the complaint to determine the ambient sound level and the amount of sound above the ambient, where a notice of violation is issued whenever needed. Unfortunately, the combination of limited human resources, the transient nature of sound, and the relative low priority of noise complaints causes slow or in-existent responses that result in frustration and disengagement.

New York City noise has been the focus of a plethora of studies investigating: noise levels in relation to air pollutants and traffic [10,11], noise exposure from urban transit systems [12–14] and noise exposure at street level [15]. All of these highlight the fact that noise is an underrepresented field in urban health and found that average levels of outdoor noise at many locations around the city exceed federal and international guidelines set to protect public health. Sensing of noise conditions using 56 relatively low cost logging sound level meters (SLMs) was investigated in [11], where general purpose SLMs were used to log SPL measurements over the period of one week. These type of deployments can help to identify noise patterns over short periods of time with respect to other factors such as traffic intensity, but are lacking in their ability to monitor noise over longer duration's. Long term noise monitoring is required to allow health researchers to perform better epidemiological studies of environmental contributions to cardiovascular disease [16].

With its population, its agency infrastructure, and its ever-changing urban soundscape, NYC provides an ideal venue for a comprehensive study and understanding of urban sound.

1.2. Type certification and IEC 61672

In order for a piece of equipment to be suitable for acoustic measurement purposes, it should comply with the sound level meter (SLM) standard IEC 61672-1 [17]. This includes, for example, tolerance limits for a device's frequency response, self-generated noise and linearity. Two "type" specifications are defined where type 1 devices, designated Precision, are intended for accurate sound measurements in the field and laboratory, type 2 devices, designated General Purpose, are intended for general field use. The overall accuracy of the device is determined by its "type" rating. In the US, the general minimum type specification for use in noise surveying is type 2. The American National Standards Institute's 1983 ANSI S 1.4 [18] for "type" certification shares many similarities with the more recent 2013 IEC 61672-1, however, the later standard does make more demands on the sound level meter regarding accuracy, performance and calibration. It is not the intention of this paper to prove that this sensor network can be used to generate legally enforceable acoustic data for a location, but the data that it can provide will be a real-time, continuous and accurate indication of the acoustic conditions in which each sensor inhabits. This data stream will help to inform and augment urban noise enforcement procedures, e.g. optimizing the allocation of in-depth noise assessment personnel and equipment.

With the current 2013 IEC 61672-1 standard for type ratings, a traditional MEMS microphone does not allow for the full set of test procedures to be carried out. The MEMS diaphragm is electrically connected to the pre-amplifier stage within the microphone's casing which does not allow for the direct injection of an electrical test signal to this internal pre-amplifier as defined in Section 5.1.16 in IEC 61672-1:

> *5.1.16 The microphone shall be removable to allow insertion of electrical test signals to the input of the pre-amplifier.*

Thus, MEMS microphones cannot currently be granted a type rating using the 2013 IEC specifications. Future revisions to the standard would surely benefit from an expansion to handle the ever advancing MEMS microphones as the sensing component for low-cost and scalable noise monitoring solutions.

2. A high quality & scalable acoustic sensor network

The last decade has produced a number of different approaches for environmental noise monitoring. These static acoustic sensor networks vary from expensive, dedicated acoustic monitoring stations to low-cost examples that make use of consumer grade hardware. Advances in low-power computing, microphone technology and networking have provided these dedicated stations incremental upgrades in the form of real-time data transmission capabilities, but these advancements have had the most profound effect on the more flexible low-cost sensor nodes which can now perform advanced DSP (digital signal processing) on audio data captured using high quality microphones and transmit via a number of wireless networking strategies. These statically deployed acoustic sensors can be grouped into three general categories, where sensor functionality and cost are the focus:

2.1. Category 1 – Dedicated monitoring stations

These commercial devices are designed and built for the purpose of accurate, reliable, low-noise and enforceable acoustic monitoring and as such can cost upwards of $10,000 USD. These systems generally consist of high-end, dedicated portable logging sound level meters and bespoke network hardware, encased in a weatherized housing. An example from this category is the Bruel & Kjaer 3639-A/B/C [19], which retails for ≈$15,000 USD and includes a type 1 approved microphone and analysis system with a measurement range from 25 to 140 dBA, the ability to produce 1/3 octave spectral noise data, real-time wireless data transfer, autonomous operation and a ruggedized casing for long term exterior operation. Other examples with similar specifications and price points include the 01dB OPER@ Station [20] and the Larson Davis 831 Noise Monitoring System [21]. The hardware and software used in these systems is usually proprietary and therefore does not provide the ability to customize the functionality to purposes other than basic acoustic monitoring of noise levels, except through software module purchases such as threshold based event detection typically costing upwards of $1000 per module. Whilst initial sensor costs are high, maintenance costs are generally less than in lower cost solutions due to the specialized and highly engineered nature of these devices. Deployment durations are generally in the order of a few months at a time due to the high cost of the hardware and security concerns.

2.2. Category 2 – Moderately scalable sensor network

This group consists of a combination of commercially made and research group developed devices that provide greater opportunities for larger scale deployments than those of Category 1 with varied accuracy of data. The typical price point of each node in this group is the $600 USD mark. Commercial examples include the $560 USD Libelium Waspmote Plug & Sense, Smart Cities device [22] which, amongst other things, measures simple dBA values with no type certification, to give an indication of a location's