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An averaging method for accurately calibrating smartphone microphones for environmental noise measurement

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ABSTRACT

Smartphones have become ubiquitous not only as communication devices but also as smart devices for majority of the population. The small form-factor of smartphones together with a rich set of application programming interfaces, low-power consumption, and presence of several types of sensors such as GPS, microphone, gyroscope, accelerometer, barometer etc. makes them a good candidate for building apps for measuring and monitoring various environmental parameters. However, for these apps to be useful the sensors must be first calibrated. In this paper, we focus on methodologies for accurately measuring sound pressure level and frequency spectrum using microphone built into smartphones. For this purpose, we present an averaging method for accurately calibrating a typical smartphone microphone against a reference microphone. We show experimental results illustrating that the proposed method can achieve an accuracy of ±0.7 dB for 99.7% of measurements for three Samsung smartphones. We also present results showing that it is possible to calibrate a smartphone using another smartphone calibrated using our method.

1. Introduction

Noise pollution has become a major problem for many cities due to increasing urbanization. This has resulted in increase of exposure to noise (unwanted, unpleasant, often loud sound) for people living in cities. Continuous exposure to high level of noise can cause both physiological and psychological problems such as hearing impairment, hypertension, ischemic heart disease, annoyance, and sleep disturbance [1]. Children living in noisy places have been shown to exhibit poor academic performance [2]. Low birth weight has been associated with exposure to loud noises in pregnant women [2]. Thus, there is a strong need to not only educate people about the adverse effects of the noise pollution but also to equip them with tools to monitor their exposure to noise.

Sound level meter (SLM) is the standard tool to measure sound pressure level (SPL) in dB or dBA (A-weighted to account for low sensitivity of human ear to low frequencies). However, these meters are expensive, delicate, bulky and more importantly difficult-to-use by non-professionals. With the advent of smartphones, we all carry a powerful minicomputer equipped with a variety of sensors such as microphone, accelerometer, gyroscope, GPS, barometer, and others. These sensors together with a rich set of application programming interfaces provided by the smartphone can be used to build apps for measuring sound pressure level [3], hearing-aid [4], coronary heart disease detector [5], earthquake detector [6], and pathological tremor detector [7]. For these apps to accurately process audio data it is necessary to calibrate the smartphone microphone to report not only correct sound pressure levels but also correct frequency spectrum.

Smartphones have become popular only in the last 10 years and as such there are only few reported works [8–14] on computing sound pressure level on smartphones. These works focus on urban noise mapping and use a single calibration value to correct the sound pressure level on smartphones. The calibration value is computed in laboratory by comparing smartphone response with a reference microphone using either white or pink noise. The calibration techniques reported in these papers are sufficient for mapping urban noise, however, they are not enough for many other applications such as psychoacoustics and determining frequency spectrum of a noise source to build effective noise barriers.

To make smartphones more versatile for applications which require audio processing, we propose that the calibration technique should have the following three characteristics:

Complete: calibration technique should not only calibrate for sound pressure level but also for frequency spectrum as the latter is useful in many applications such as psycho-acoustic analysis.

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Cost-effective: calibration technique should be cheap to make method accessible to large number of people and it should be fast to allow calibrating a large number smartphones necessary for large scale participatory sensing experiments.

Well-tested: The quality of microphone varies widely among various models of smartphones and it is possible that the calibration accuracy might differ among different smartphone of the same model. Therefore, it is important to sufficiently test calibration for each model and include accuracy information along with the calibration data.

In this paper, we present an averaging method for accurately calibrating smartphone microphone against a reference class 1 microphone. The proposed method calibrates smartphone microphone not only for sound pressure level but also for the frequency spectrum. Calibration and validation were both done in the field, thus expensive equipment such as anechoic or reverberation chamber is not required. Currently, there are two main smartphone platforms: iOS from Apple and Android from Google. Some existing works [15–17] have reported that iOS devices with available apps are more accurate compared to Android devices for noise measurements. Although, our method can work equally well with either iOS or Android devices we chose to test our method only on Android devices to fill this gap. We will consider iOS devices in the near future.

2. Related works

One of the first comprehensive work on calibration and noise mapping using smartphones is NoiseTube [9,18]. They used linear mapping between noise levels from phones and a reference microphone for calibration. However, we have found that the response of a smartphone microphone is linear with respect to noise level but non-linear with respect to frequency. They reported an accuracy of 0.56 dBA for noise levels under 100 dB in laboratory. In the field, the accuracy varies as expected and for an 81 min walk the mean error was 0.15 dB. For a 4-min interval during the walk the error was 2.37 dB. In the presence of wind, the error reported was as high as 10 dB.

Zuo et al. [13] presented a technique for calibrating smartphones using 1 kHz pure tone with varying amplitude to create distinctive features for automatic comparison of signals from SLM and smartphone. They did the experiment in an anechoic chamber and compared the sound pressure level computed by smartphone with the sound pressure level measured from a class 2 sound level meter. They determine a single overall calibration factor as a mean of sound pressure level differences between smartphone and reference microphone. They reported variable accuracy among smartphones tested with accuracy under 1 dB for HTC Butterfly, Samsung S3, and Unistrong J4; and accuracy over 2 dB for iPhone 6S and a second Unistrong J4. These results are based on only 10 measurements with unknown lengths. It seems that all five phones were tested at the same time using a single reference microphone. The large distance between reference microphone and smartphone microphone will affect the error between two instruments due to directional sound, reflections, etc. It might also be the reason for large difference in error (0.59 vs 2.71 dB) between two models of Unistrong J4. In contrast, we measure with only one smartphone at the time and keep the reference microphone and smartphone microphone aligned.

Zamora et al. [19] presented and compared accuracy of three noise calculation algorithms with respect to the sampling frequency and block size (length of measurement). Their method does not calibrate phone per se but determine the values of the sampling frequency and block size which will produce the least error in noise measurements. There are two side effects of this approach: loosing high-frequencies and lower frequency resolution. They reported that the errors in noise levels can vary from 1% to 12% depending on the value of these two parameters.

Rajib et al. [12] presented a context aware technique for noise mapping using smartphones. They built classifiers to detect the location (hand, pocket, or bag) of phone and automatically determine when to start measuring. They used an in situ calibration technique, where phone plays a reference sound and at the same time record it. The reference sound is compared with the recording to determine calibration factors. It is, however, not clear how this technique will work as audio level of the sound played on phone depends on several factors such as volume control, equalizers, phone casing, etc. Their measurement accuracy varies from 2.5 to 4.91 dBA depending on the context when compared with sound pressure level measured with a class 2 sound level meter.

Navarrete et al. [3] presented a design of sound level meter. They used a single offset to calibrate the sound level meter against a reference microphone and can achieve an accuracy of class 3 sound level meters (±3 dB). There are few other reported works Aumon et al. [14], NoiseCo [11], NoiseMap [8], and NoiseSpy [20] on noise mapping which use single overall calibration factor. The calibration method in these works are similar and the error is either not reported or is 1.5 dB or more.

There is a plethora of apps on both Google Play Store (Android) and Apple App Store (iOS). Most of the apps available comes with either no calibration or allow a user to specify a single offset to adjust the reported sound pressure level. There are some reported works which compare the accuracy of sound level meter apps for both Android and iOS [15–17]. These studies reported that iOS apps are superior in accuracy compared to Android apps. One potential reason for this discrepancy is that there are only few variations of iPhone in terms of hardware but there are many variations in devices when it comes to Android based smartphones. Kardous and Shaw [21] found that using an external calibrated microphone improves the accuracy of sound level meter apps to within ±1 dB of reference. In [22], Celestina et al. presented calibration method used by NoiSee app available for iOS devices. They showed that NoiSee app running on iOS devices with MicW type i436 external microphone can achieve compliance with most of the requirements for Class 2 of IEC 61672/ANSI S1.4-2014 standard.

3. Measuring noise levels on smartphone

A smartphone captures audio from its microphone and digitizes it to an audio buffer consisting of floating-point numbers proportional to the input sound pressure. To use a smartphone as a sound level meter, an app running on the smartphone has to compute sound pressure level and frequency spectrum from the input audio buffer.

According to the current international standard for sound level meter, IEC 61672-1:2013 [23], sound level meter should also include support for A- and C-frequency weighting. A-weighting compensates for the fact that human ear is less sensitive to low frequencies. A-weighted L_{eq} or LA_{eq} is reported in dBA and is commonly used for measuring environmental noise. The response of the human ear depends not only on frequency but also the noise level. At high noise levels (>100 dB), the ear's response is flatter and is represented by C-weighting. C-weighted L_{eq} or LC_{eq} is reported in dBC. C-weighting is frequently used for signals with significant low frequency content, such as airport noise.

A- and C-frequency weighting can be implemented in the time-domain using digital filters or in the frequency-domain. Since our goal is to compute not only sound pressure level but also frequency spectrum we have implemented frequency weighting in the frequency domain as specified in IEC 61672-1:2013 [23]. Fig. 1 illustrates the process of calculating sound pressure level and frequency spectrum from the audio buffer: