A case study of smartphone based platform for mapping and analyzing environmental noise in Singapore

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Abstract. In this paper, we present a smartphone based platform for mapping and analyzing environmental noise. Smartphones are used to record environmental noise (both audio and sound pressure level) as well as locations (latitude, longitude, and accuracy). The recorded data is uploaded to a server and noise map of a region is generated using the location information along with the sound pressure levels (SPL) at those locations. Noise maps can be used to discover sources of noise in a region and also to compare SPL between different places. Thus, they can be an important tool to help implement mitigating steps for reducing noise or planning future developments. To illustrate the capabilities of the platform, we present a case study of noise mapping with five educational institutes and five residential neighborhoods in Singapore. We present noise maps for these places and discuss possible sources of noise. We also discuss potential reasons for observed differences in equivalent continuous sound pressure level between different educational institutes, and residential neighborhoods.

1. Introduction
Noise pollution has been on the rise due to increasing urbanization of cities. Increase in environmental noise levels has adverse physiological and psychological problems not only in humans [1, 2] but it also affects biodiversity in cities [3]. Thus, it is important to monitor environmental noise and take actions to provide suitable living and working environment. Traditionally, environmental noise monitoring has been done using few static measurement stations installed in the region to be monitored. Static stations can only provide noise data at the installed locations with no information in other places. However, with the advent of smartphones which are equipped with a microphone and GPS providing accurate location of the smartphone, it is possible to build a noise map of a region. A noise map is like a weather map but for noise. It uses color to show the sound pressure levels in a region (Figure 1). Noise maps can be used to discover sources of noise in a region and also to compare sound pressure levels between different places. Thus, they can be an important tool to help implement mitigating steps for reducing noise or planning future developments.

There are few reported works in literature for building environmental noise map. One of the first works on noise maps was NoiseTube [4]. The authors combined GPS information with noise data collected by smart phones to generate noise maps. Similar works were reported by Kanjo [5] and Schweizer et al. [6]. Rajib et al. took a different approach in [7] by building classifiers to
detect the location (hand, pocket, or bag) of phone and automatically determine when to start measuring. This frees user from actively starting measurements and arguably more data can be collected. Shim et al. [8] conducted a study to determine feasibility of noise mapping using volunteers or citizen scientists. They were able to build a noise map of Seoul using 336 volunteers over a period of seven days. Data was recorded by each volunteer’s phone automatically at 10 minutes interval. Zuo et al. [9] used an external microphone with a wind screen connected to smartphones to build noise maps. External microphone frees users from holding smartphone in their hands and pointing them correctly for a long period of time. Wind screen helps to reduce effects of movement of subjects and wind. They also proposed an interpolation method to build very detailed noise maps with the limited measured data.

In this paper, we present a system for recording environmental noise maps using Android based smartphones. We illustrate our system with two case studies in Singapore. The first case study compares noise levels in five educational institutes (polytechnics) and the second case study compares noise levels in five residential neighborhoods in Singapore.

2. Noise Mapping Platform

We have developed an Android app known as NoiseExplorer for measuring sound pressure level (SPL) using smartphones. NoiseExplorer gets the audio data from the built-in microphone of a smartphone and computes instantaneous dBA (A-weighted SPL). Additionally, NoiseExplorer also keeps track of the minimum, maximum and continuous equivalent (average) SPL for the current session. The user can choose to show either a live frequency spectrum or the current location of the smartphone on Google Maps using Google Maps Android API.

The locations and noise levels are recorded in a log file and are used to generate noise map. The data is logged to the file at a user specified frequency (default is five seconds because it is the fastest speed at which Google maps updates location). The user can optionally choose to record the audio as uncompressed WAV files. Although uncompressed WAV files occupy more space compared to compressed formats such as mp3 or aac, we chose WAV so that we can perform spectral and psychoacoustic analysis on the recordings. For most smartphones, the storage is not an issue these days, moreover, users can delete recorded WAV file or move them to an external storage device or micro SD cards once they have uploaded them to the server (or even without uploading). At present WAV and log files are stored on the smartphone itself and manually uploaded to a server after all measurements are finished. The server then generates noise maps from the log files. It is also possible to generate average spectrum and spectrogram from WAV files. Finally, the user can specify a calibration file containing a set of frequency and...
correction factor pairs. The correction factors for frequencies not present in the calibration file are linearly interpolated. Figure 2 presents some screenshots of the app.

3. Case Studies

We have used NoiseExplorer app to record noise map for various places in Singapore and around the world. In this paper, we will present noise maps for five polytechnic institutes and five residential neighborhoods in Singapore. The noise maps were recorded by four smartphones: Samsung Galaxy S7 (relatively new), two different Samsung Galaxy S4 (both old and used), and a ZTE Blade Q Pro (low-cost about 60 USD). A team of four students walked with smartphone in the ten areas in Singapore to record noise levels. The data analysis and noise map generation was done offline on a computer.

The noise maps for five polytechnics are presented in Figure 3. The major source of noise in all five polytechnics are canteens and other areas where a lot of students gather around. Singapore and Ngee Ann polytechnic are next to major trunk roads and traffic noise is prominent for areas adjacent to roads. Table 1 shows the $L_{eq}$ (continuous equivalent SPL) and $L_{max}$ (maximum SPL) for all five polytechnics. Nanyang polytechnic is about 3dB noisier than other polytechnics because they have a child care center on campus and at the time of measurement there were couple of buses to pick children up from the center with many children running around. Additionally, they happened to have an event on campus with many people talking during measurement.

The noise maps for five residential neighborhoods are presented in Figure 4. The major source of noise in all five neighborhoods is traffic with occasional people talking and wind noise. Table 2 shows the $L_{eq}$ and $L_{max}$ for all five neighborhoods. Chai Chee is the quietest because most of the measurements are away from any major trunk road and Jurong West is noisiest because most of the measurements are next to a major trunk road with high traffic. Many measurements for Choa Chu Kang and Clementi were taken near train tracks and hence noise levels are high. For Woodlands, many measurements are near train tracks and major trunk roads, however, there are measurements down in park and other internal locations with less traffic thereby reducing the overall noise level.

4. Conclusions

In this paper, we presented an overview of the smartphone based platform for mapping and analyzing environmental noise. We discussed NoiseExplorer app for computing and recording sound pressure level along with location information via GPS. The location information with
(a) Nanyang Polytechnic  (b) Ngee Ann Polytechnic  (c) Republic Polytechnic  
(d) Singapore Polytechnic  (e) Temasek Polytechnic

Figure 3. Noise maps for five polytechnics in Singapore.

Table 1. Noise levels for five polytechnics in Singapore.

| Polytechnic | LAFeq (dBA) | LAFmax (dBA) | Duration (hh:mm:ss) |
|-------------|-------------|--------------|---------------------|
| Nanyang     | 71.4        | 89.1         | 00:31:53            |
| Ngee Ann    | 68.0        | 89.2         | 00:35:05            |
| Republic    | 68.4        | 89.6         | 00:29:58            |
| Singapore   | 68.8        | 93.1         | 01:04:26            |
| Temasek     | 65.9        | 91.4         | 00:56:48            |

sound pressure levels is used to generate noise maps. Noise maps can be used to find sources of noise in a region and also allows to compare different regions in terms of sound pressure levels. We presented two case studies comparing noise levels among five polytechnic institutes and five residential neighborhoods in Singapore.

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Figure 4. Noise maps for five residential neighborhoods in Singapore.

Table 2. Noise levels for five residential neighborhoods in Singapore.

| Neighborhood  | LAFeq (dBA) | LAFmax (dBA) | Duration (hh:mm:ss) |
|---------------|-------------|--------------|---------------------|
| Chai Chee     | 66.1        | 87.9         | 00:31:46            |
| Choa Chu Kang | 70.4        | 90.3         | 01:17:11            |
| Jurong West   | 71.1        | 94.0         | 00:22:15            |
| Clementi      | 69.8        | 86.9         | 00:25:04            |
| Woodlands     | 68.8        | 90.4         | 01:02:40            |

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