NoiseTube: Measuring and mapping noise pollution with mobile phones

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Abstract

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NoiseTube: Measuring and mapping noise pollution with mobile phones

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Abstract:
In this paper we present a new approach for the assessment of noise pollution involving the general public. The goal of this project is to turn GPS-equipped mobile phones into noise sensors that enable citizens to measure their personal exposure to noise in their everyday environment. Thus each user can contribute by sharing their geo-localised measurements and further personal annotation to produce a collective noise map.

Keywords: Noise pollution, citizen science, participatory sensing, people-centric sensing, geo-localisation, tagging, mobile phones.

1. Introduction

Noise pollution is a major problem in urban environments, affecting human behaviour, well-being, productivity and health [11], as well as the behaviour and habitat of animals [30]. Recognising this as a prime issue, the European Commission adopted a directive [12] requiring major cities to gather real-world data on noise exposure in order to produce local action plans [13].

Numerous international reports (e.g. Principle 10 of the Rio Declaration on Environment and Development) have expressed the importance of public participation to move towards sustainable development. But often participation is only proposed at the decision making level. Could citizens also participate in the assessment of environmental issues? Can we transfer the user-generated content practices from the digital world (cfr. Web 2.0 [17]) into a real-world and environmental context by democratizing environmental measurement devices? How will the practice of pollution monitoring change if every citizen can contribute to it using personal mobile environmental measuring devices?

In this paper we present the NoiseTube project[1], which follows a novel approach to noise pollution monitoring involving the general public. Our goal is to investigate how participative and people-centric data collection can be used to create a low-cost, open platform to measure, annotate and localise noise pollution as it is perceived by the citizens themselves. In continuation of earlier research, we want to apply the potential of *community memories* [27, 28] and *citizen science* [19] to noise monitoring.

The next section provides an overview of current and alternative methods for the assessment of environmental noise. Then we describe our approach in section 3 and our prototype platform in section 4. Next, section 5 we discuss the credibility of the sensor data and section 6 provides additional background and discussion. Finally, section 7 concludes this paper.

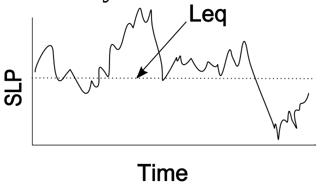
2. Assessment of environmental noise

2.1 Noise level measurement

Noise level or loudness is generally measured as the equivalent continuous sound level or L_{eq}. Measured in decibel (dB), L_{eq} captures the sound pressure level of a constant noise source over the time interval *T* that has the same acoustic energy as the actual varying sound level pressure over the same interval. Furthermore the human ear perceives the loudness differently depending on the frequency of the sound. Standard “weighted scale” frequency functions have been developed to reflect human perception, notably the A-weighting scale, written dB(A) is commonly used.

$$L_{eq} = 10\log\frac{1}{T}\int_0^T \frac{p^2}{p_0^2}\,dt$$

p = sound level pressure (SLP) recorded
p_0 = minimal audible SLP



[1] http://www.noisetube.net

2.2 Traditional measuring approach

Nowadays noise assessments in urban areas are usually carried out by officials who collect data at a sparse set of locations, e.g. close to roads, railways, airports and industrial estates, by setting up sound level meters during a short period of time. Propagation models are then used to generate noise maps by extrapolating local measurements to wider areas. This practice has a number of limitations:

Spatio-temporal data granularity: computational models often produce results with an unknown error margin, which may lead to incorrect conclusions regarding caused uncomfort [16]. As stated by the EU practise guide [13] real data with high granularity in both time and space is required. However, data collection at sparse locations hardly scales to meet such requirements. Furthermore, strategic noise mapping only allows detecting general noise conditions. How can we monitor unusual local or short-term noise pollution?

Cost: the cost of such noise mapping campaigns is high due to the need of expertise and human resources, the deployment of expensive sound level meter equipment and the processing effort. This restricts cities with limited budgets from conducting such assessments.

Public noise exposure assessment: the EU practise guide [13] requires detailed assessment of the level of noise citizens are actually exposed to. However, few efforts have been done to combine noise mapping and population data to assess the noise exposure of citizens [26].

Indoor noise assessment: current noise mapping only covers environmental noise, i.e. outdoor noise. However, most people spend a significant portion of their time indoors.

Fig. 1. Official noise map of Paris generated using a propagation model and measurements made at a limited number of locations and times. Quiet areas are coloured in green while noisy places are in purple. Gray areas represent places for which no information is available (e.g. in buildings).

2.3 Alternative approaches

2.2.1 Wireless sensor networks

Recent years have seen an increasing interest in wireless sensor networks (WSN) for environmental monitoring [23] and urban sensing [8]. Wireless sensor networks have the potential to revolutionize environmental assessment, notably regarding spatio-temporal granularity. Rather than relying on a limited number of expensive, accurate, stationary sensing equipment, a WSN uses large numbers of cheap, simple, compact sensor devices. Sensors can be directly embedding into the environment and operate continuously, enabling real-time monitoring of environmental phenomena or human activities. A recent example of using WSNs for noise monitoring is discussed in [24]. In this project custom-made noise sensors were placed at fixed locations in the city. However, it remains questionable whether this is cheaper than traditional approaches for large-scale deployments.

2.2.2 Participation of citizens

To implement the requirements of the European Noise Directive [12] – END for short – involvement of citizens is key. This is especially important with regards to local action plans, which often directly affect people living nearby. But citizens can also contribute in earlier phases, such as the actual assessment of noise pollution.

In geography and urban planning there is also trend to support such participation. Under the flag of *participatory GIS* [7] new methodologies are being researched to better support the participation and involvement of citizens in projects that are typically tackled using geographical information systems (GIS). An interesting example in the context of noise pollution monitoring is [9]. In this project researchers equipped volunteers with noise level meters to create noise maps accessible through an online GIS system. However the need for rather expensive professional devices could limit the creation of real-world campaigns initiated by communities.

3. Approach

Taking inspiration from wireless sensor networks and the trend towards participation of citizens we intend to use GPS-equipped mobile phones as noise sensors and involve the citizens that carry them to measure, locate and provide qualitative input for the monitoring of urban noise pollution. In this section we discuss and motivate this approach in detail.

3.1 Mobile phone as an environmental sensor

The growing popularity of smart phones with high computational power, Internet access and integrated sensors (e.g. cameras, GPS, motion sensors) represent a cheap but powerful WSN platform that is readily available and widely deployed. In this perspective mobile phones can serve as sensors which are carried by humans rather than placed at static locations. In addition to carrying around sensors, citizens can also be more directly involved in the sensing process by entering qualitative inputs (noise source tagging, annoyance rating). Thanks to the aggregated mobility of users, this approach enables sensing coverage of large public spaces over time long periods of time.

3.1.1 Mobile sensing

This idea is related to the concept of *participatory sensing* [4], which advocates the use of mobile devices to form sensor networks that enable public and professional users to gather, analyze and share local knowledge. At the same time, people as individuals or in groups can apply these new sensing networks with a more personal focus. Their individual stories of everyday life can be aggregated to document the urban environment, fed back into a collective experience in urban public spaces, enabling *people-centric sensing* [5], for personal, peer or public purposes.

3.1.2 Democratising noise pollution measurement

Despite some research projects involving volunteers and specific measurement devices, e.g. for air pollution monitoring [21] the participatory sensing paradigm has not been validated empirically by real world use in an environmental domain due to the cost and lack of access to environmental sensors for the general public. In the context of noise pollution, by turning mobile phones into noise pollution sensors, we strongly lower the entrance barrier of such environmental measurement technology. NoiseTube has the potential to set up new kinds of experiments by enlarging the scope of potential participants. In the spirit of the Web 2.0 culture [20] and its user-generated content model, we expect novel mobile device applications and networked participation models to emerge for environmental monitoring (e.g. for noise pollution) that fully tap into the potential of citizen science [22].

3.2 Measuring pollution at the individual level

3.2.1 A persuasion tool

Giving the possibility to any citizen to measure their personal noise exposure in their daily environment could influence their perceptions and potentially support the raising of awareness of environmental issues, the first stage in the adoption of new behaviour [22]. Personalized pollution information could have a bigger impact than general statistics provided by environmental agencies to change habits towards a more sustainable lifestyle. With its ubiquity, the cell phone has already demonstrated its value as a persuasion tool in several cases (education, health and marketing) [14] and may have an equally big potential in an environmental context.

3.2.2 People- vs. place-centric exposure

As described in [4], people can use participatory sensing instruments in the context of grassroots campaigns to collect pollution measures at specific locations. In a sense, this is a mobile extension of what is often done using (statically deployed) wireless sensing networks. The cell phone is also situated in an environment typically co-located with the user. Therefore, it could be used as a tool to self-monitor one's individual exposure to inform the community about it. The usefulness of such people-centric data has been demonstrated in health-related projects such as [29], in which children were equipped with sensors for air pollution to understand the factors affecting asthma. Measuring noise pollution, not only from a geographical point of view, but also through the people's exposure opens potential links with epidemiological studies at a larger scale.

3.3 Enabling participatory culture

3.3.1 Supporting local democracy and citizen science

The NoiseTube project is situated in the growing movement of local democracy. We intend to provide tools for citizens to collect fine grained data (e.g. evidence of harmful noise exposure levels) to convince local authorities and influence decision making on local issues, without waiting for officials to gather the data. We envision that the NoiseTube web platform could serve as a tool to help existing organisations (e.g. groups focused on well-identified noise pollution problems, such as in communities close to airports) to gather credible data.

3.3.2 Social translucence mechanism

NoiseTube uses the concept of social translucence consisting in making participants and their activities visible to one another. The role of social translucence is to inform, to create awareness and to enforce accountability [10]. These mechanisms also influence the level of the motivation of the individual and the group via social stimulation happening via social comparison [15], by reinforcing the perception of self-efficacy in a social context [1] or by displaying the value of contribution [25]. As pointed out in [6] despite the individual use of popular Web 2.0 services, such as Wikipedia and YouTube, opportunistic cooperation emerges among individuals due to interactions (e.g. comments) created by the visibility of their personal productions. Thus by making individual noise exposure public we intended to create opportunities to forge new relations among people facing to similar problems, which can then result it collective action, overcoming the *cold start effect*.

3.3.3 Unconstrained participation

Even though the ubiquity of mobile phones makes mass participation feasible, as attempted in [5, 20], it remains questionable how the general public can be motivated to voluntary do so. How to involve the hidden majority of citizens who do not participate in local organizations and want to use such technology for personal purposes? In our noise pollution context, the goal is to not force people to make their measures public and thus to always contribute at to a collective mapping process. By allowing users to choose if they want to share or not all or a part of their measurements, we also want to avoid privacy concerns.

4. NoiseTube platform

The current prototype of the NoiseTube platform consists of an application which the participants must install on their mobile phone to turn it into a noise sensor device. The mobile sensing application runs on GPS-equipped mobile phones. This application collects local information from different sensors (noise, GPS coordinates, time, user input) and sends it to the NoiseTube server, where the data is centralised and processed.

4.1 Measuring loudness in real time

The mobile application contains a real-time signal processing algorithm which measures the loudness level of the microphone recording the environmental sound (at 22500 Hz, 16 bits) over 1 second at a chosen interval. An A-weighting filter is then applied to the recorded sound and the equivalent sound level (L_{eq})[2], measured in dB(A), is computed.

The calculated loudness is displayed (see Fig. 2) in real time using a graph and as a value in dB(A). To add meaning to this value it is associated with a colour that represents the health risk of the current exposure level: < 70: green (no risk); > 70 and < 80: yellow (be careful); > 80: red (risky).

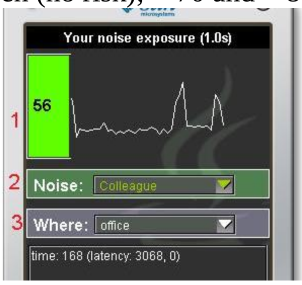


Fig.1 – The Mobile sensing application. Including 3 components: (1) The visualization of the loudness measured and a color representing the danger (2) The noise tagging (3) The tagging of the location (for indoor location for instance)

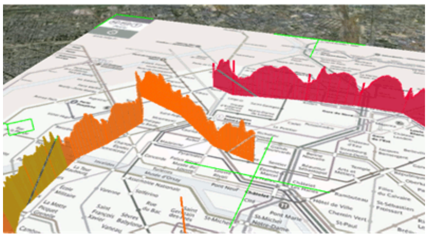


Fig.2 - Noise map of two subway lines (indoor location) reconstructed thanks to the geo-tagging feature in the mobile sensing application

4.2 Tagging

In addition to measured loudness, public noise maps often only provide very limited information regarding the source or context of noise. This sort of semantic information is vital to make such maps meaningful for both citizens and decision makers.

Environmental tagging: In order to better support this, users can directly annotate sound in specifying the source of a noise (e.g.: cars, aircraft, neighbours) and give an annoyance rating or any additional contextual information in the form of free words (tags).

Geo-tagging: Because indoor positioning is virtually impossible with GPS (see 5.2), we let users precise their location using a map or a list of favourite places (e.g. “home”, “office”). Afterwards this information can then be matched with actual coordinates. For example, by specifying subway stations a path followed in the subway can be reconstructed afterwards (see fig. 3).

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[2] L_{eq} is the standard loudness measure as required by the END [12].

4.3 Visualising noise maps

Once the measured data is sent the server, any user can see his own contributions or exposures by going to the NoiseTube website and visualize them on a map using Google Earth. A collective noise map is also publicly available. This map is constructed by aggregating all the shared measurements. Each map can show a layer of tags entered by participants to add context and meaning to the loudness data. A real time monitoring of the loudness readings of all participants is also available.

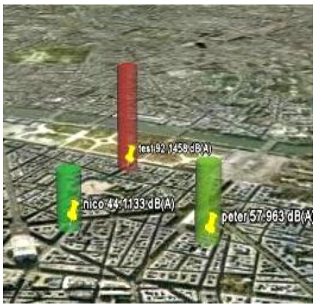

Fig. 3 – Visualisation with Google Earth. On the left, the collective noise map generated by all the measures. On the right, a real time visualization of the collective noise exposure.

4.4 Building environmental exposure profiles

As mentioned before we have attempted to develop features related to the concept of social translucence to motivate and create accountability. Inspired by the concept of blogs with developed the idea of an *Elog*, or "Environmental Log". In our noise pollution context, an Elog would enable individuals to show their life through their current noise exposure or their contributions to the noise monitoring of their city. Thanks to this public profile we also attempt to support opportunistic connection and interaction among people facing similar problems.

4.5 Web API to access public data

Currently, the raw measures are generally not directly accessible for public or scientists, limiting their exploitations by third-parties. The EC directive [12] requires only a web user interface to improve the accessibility of noise maps for the public. To avoid creating an inaccessible information silo we want to go further than that. Therefore, the NoiseTube platform exposes a simple web API for publishing or accessing data. Using this API scientists or developers can use individual or collective noise exposure data to create web mash-ups or analyse data for scientific purposes.

4.6 Implementation

The current version of the mobile application was written in Java and is aimed primarily at smart phones running the Symbian/S60 operating system. The program was mainly tested on a Nokia N95 8GB smart phone. Although untested, many other phone brands[3] and models are supported as well, as long as the device supports the Java J2ME platform, with multimedia and localisation extensions[4]. A GPS receiver (built-in or an external unit that is connected via Bluetooth) is needed to localise measures. A version for the Apple iPhone is also planned. The server side is implemented using Ruby on Rails, MySQL, Google Maps and Google Earth.

5. Data credibility

The credibility of measurements is fundamental issue of low-cost sensing.

5.1 Mobile phone as Sound Level Meter

Without proper calibration, sensor devices produce data that may not be representative or can even be misleading. Experimentation has been conducted to measure the precision of the loudness computed with a mobile phone compared to a sound level meter[5]. We generated a pink noise at different levels of decibels (every 5 dB, from 30 to 105) and measured the results of our algorithm on the Nokia N95 8GB.

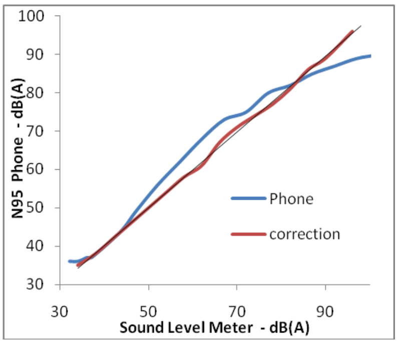

Fig. 5. Blue line: results of the distortion of the N95 phone's microphone compared to a sound level meter in the computation of the loudness (L_{eq}). Red line: results after applying post-processing.

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[3] Initial tests with Sony-Ericsson phones are underway.

[4] To be exact the phone should support Java J2ME profile CLDC v1.1 with MIDP v2.0 (or newer), JSR-179 (Location API) and JSR-135 (Mobile Media API).

[5] We used a Voltcraft SL 100, rated DIN EN 60651 Class 3 (precision ± 2.5 dB)

The blue curve on figure 5 shows the response of the microphone compared to a sound level meter. According to this result this phone can be used as a sound level meter in the interval [35, 100 dB] due to the curve's bijectivity. After applying the inverse function as a post-processing corrector we obtained results with a final precision of ± 4 dB (red line).

5.2 Positioning accuracy

Using the Nokia N95 8GB with its built-in GPS chip an acceptable level of positioning accuracy in outdoor situations can be achieved. Errors are rarely bigger than 30 meters, which is still good enough to localise noise sources within a specific neighbourhood or street. When using an external GPS receiver positioning accuracy can be slightly improved and the start-up time is generally shorter. Using an external receiver also has the added benefit that the phone's battery life is less affected. However, in both cases indoor positioning is virtually impossible.

6. Discussion and future work

Democratisation of technologies such as NoiseTube will bring new applications and new questions for the participatory sensing paradigm.

6.1 Roles of citizens

How to sustain a human network at a larger scale and for a longer time than a local and short-term experimentation or campaign? How to design a network mixing humans and machines to monitor environmental resources? As far as we know, these questions have not been tackled yet by the current research on participatory sensing due to the small amount of participants and so the lack of complex structures. No explicit network topology has been used for the experimentation except the basic 'stars' topology. But further investigation could take advantage of social relationships, shared interests or reputation (expert/scientist) among the participants as a solution for problems as data and analysis credibility by using them not only as sensors but also as filters or regulators.

6.2 Soundscape assessment

Besides the widely deployed loudness measure in noise annoyance research, several studies have shown that acoustics alone can only explain part of the subjective evaluation of annoyance to sounds [32]. As a consequence other important aspects in the experience of sound perception are underexposed. It has been shown that things such as the visual aspect, temperature, wind and sunshine can all influence the evaluation of a *soundscape* [29]. Democratising noise pollution measurements provides a way to gather a most complete picture of the subjective experience, since it can incorporate acoustic measurements as well as subjective assessments.

6.3 User feedback and awareness

The user experience, especially with the mobile phone application, is crucial to motivate users to contribute. Even though the current version allows users to visualize noise exposure in real-time, we would like to improve the feedback by giving interesting insights coming from the collective experience, e.g. a map to highlight unusual pollution measured by other participants, in order to support local decision-making. Furthermore, we are planning to develop more features related to the social translucence to sustain motivation, accountability and participation.

6.4 Data credibility at the collective level

Until now we have focussed on the credibility of the sensors (microphones, GPS). However, once a collective collection of noise data is underway we will also need to deal with data credibility among users, e.g. in case of contradictory measurements. This will affect the way the system aggregates, analyses and filters measurements.

7. Conclusion

In this paper we presented NoiseTube, a project aimed at developing a participative noise pollution monitoring network to enable citizens as well as governmental bodies and non-governmental organisations to gain awareness of and insight into the problem of urban noise pollution and its social implications. We discussed our approach and the supporting rationale as well as a prototype implementation. While this project is still in an early stage we are planning to open up a first public experiment soon to evaluate user experiences and participation, as well as the credibility of the generated noise maps compared to traditional ones.

8. Acknowledgements

This work was partially supported by the EU under contract IST-34721 (TAGora). The TAGora project is funded by the Future and Emerging Technologies program (IST-FET) of the European Commission. Matthias Stevens is a research assistant of the Fund for Scientific Research, Flanders (*Aspirant van het Fonds Wetenschappelijk Onderzoek - Vlaanderen*).

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