Crowdsourcing of Pollution Data using Smartphones

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ABSTRACT
In this paper we present our research into participatory sensing based solutions for the collection of data on urban pollution and nuisance. In the past 2 years we have been involved in the NoiseTube project which explores a crowdsourcing approach to measuring and mapping urban noise pollution using smartphones. By involving the general public and using off-the-shelf smartphones as noise sensors, we seek to provide a low cost solution for citizens to measure their personal exposure to noise in their everyday environment and participate in the creation of collective noise maps by sharing their geo-localized and annotated measurements with the community. We believe our work represents an interesting example of the novel mobile crowdsourcing applications which are enabled by ubiquitous computing systems. Furthermore we believe the NoiseTube system, and the currently ongoing validation experiments, provide an illustrative context for some of the open challenges faced by creators of ubiquitous crowdsourcing applications and services in general. We will also take the opportunity to present the insights we gained into some of the challenges.

Author Keywords
Ubiquitous computing, crowdsourcing, environmental sustainability, pollution measurement, participatory sensing, citizen science, mobile phones.

ACM Classification Keywords
H.5.2 Information interfaces and presentation (e.g., HCI): Miscellaneous.

General Terms
Measurement, Human Factors, Reliability, Experimentation.

INTRODUCTION
The technologies that are bringing Mark Weiser's vision [17] of ubiquitous computing into the reality of everyday life are also enabling a breed of applications and services which have been labelled as urban, participatory or people-centric sensing [5, 3, 4]. Many such applications involve crowdsourcing: the collection of information or analysis of data by engaging networked people. Often user's mobile devices become nodes in a sensor network that serves to gather, analyse and share local knowledge. The individual mobility patterns and stories of everyday life of contributors can thus be aggregated to document an entire urban environment.

Crowdsourcing pollution data
Given the growing global concerns – in academia, politics and society at large – about environmental sustainability in general and climate change [9] in particular, computer science should take up its responsibility in the quest for a sustainable human society. Along with many others [13, 18, 7] we believe that ubiquitous computing and sensing technologies can play and important role in this respect.

Our research is centred around the idea that ubiquitous crowdsourcing and participatory sensing solutions lend themselves not only to monitoring the state of the physical world (e.g. measure pollution levels) but can at the same time also contribute to raising people's awareness of the issues at hand. Therefore the motivation for involving the general public in pollution assessment is twofold.

On the one hand we believe crowdsourcing systems can complement current assessment techniques to achieve higher degrees of spatio-temporal granularity at lower costs. Economic theory provides an interesting background here. Many pollution issues can be seen as so-called common-pool resource (CRP) problems. In the case of atmospheric pollution the shared resource would be (clean) air and for noise pollution the resource at stake can be seen as silence and thus quality of life. One of the principles of the governance of commons, as introduced by Nobel price for Economics winner Elinor Ostrom [12], states that it is necessary that "resources can be monitored, and information can be verified and understood at relatively low cost".

On the other hand by effectively putting measurement devices into the hands of average citizens we are directly confronting them with the pollution they are exposed to and for which they are sometimes (indirectly) partially responsible. This is of great importance because pollution cannot be tackled by policy makers alone, as it requires consideration of the behaviour of all citizens. It is no surprise that numerous international reports [16, 8] have expressed the importance of participation of all involved citizens, at all levels, to

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move towards sustainable development. By turning smartphones into personal measurement instruments, we strongly lower the barrier to environmental measurement technology to achieve a democratisation of the monitoring process.

These arguments and other reasons why we believe public participation (and thus crowdsourcing) makes sense for pollution assessment are discussed in detail in [6] and [11].

CASE: NOISE POLLUTION

In [10, 11] we proposed a low-cost approach to noise pollution monitoring, under the name *NoiseTube*, which involves the general public and uses mobile phones as noise sensors.

We chose to focus on noise pollution because it is a major problem in urban environments, affecting human-behaviour, well-being, productivity and health [2]. Furthermore we expect that it can serve (to some extent) as a proxy for other, harder to measure, forms of pollution. The choice also allowed us to experiment with participatory sensing solutions using only off-the-shelf devices, since we can measure the level of noise using the internal microphone of a mobile phone (measuring atmospheric pollution would have required expensive external sensors).

More information on noise pollution and a comparison between our approach and more traditional methods of assessing it are provided in [11].

NOISETUBE PLATFORM

The NoiseTube platform consists of two components, the mobile application and the Web-based community memory.

Mobile application

The mobile application[1] can be downloaded for free from the NoiseTube website [1] and installed on compatible phones [15] to turn them into mobile noise sensors. It collects information from different sensors (microphone, GPS receiver, user input) which is logged locally and/or sent to NoiseTube community memory server in real-time. The photo in Figure 1 shows this application in use. The main features are:

Noise exposure measurement: a signal processing algorithm computes the sound level ($L_{eq,1s}$ measured in dB(A)) the user is exposed to by taking 1 second-long audio samples recorded using the phone's microphone. Repeating this process results in a series of measurements which are shown on screen as numeric values and on a histogram. Because different mobile phones have different microphones the algorithm needs to be calibrated for particular models.

Geo-tagging: using a GPS receiver (built-in the phone or external) each noise level measurement is tagged with geographical coordinates (WGS84).

Social tagging: taking inspiration from [14], we enable users to directly annotate or tag sound level measurements using the mobile application. These tags can describe the source of noise (e.g.: "car", "airplane", "neighbours"), subjective impression (e.g.: "loud", "annoying"), etc.

[1]Targeting the Java J2ME CLCD/MIDP platform, still found on the majority of smartphones in the market.

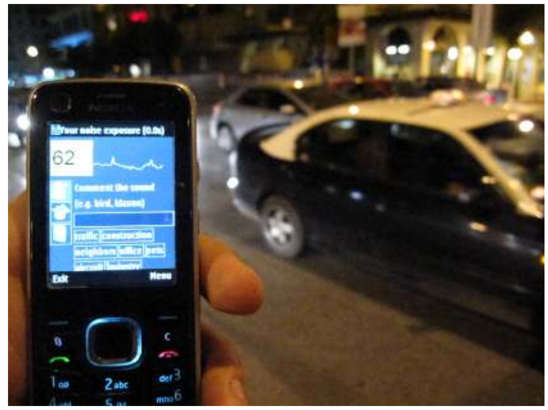

Figure 1. The NoiseTube Mobile application in use in a busy street in Thessaloniki, Greece

Web-based Community Memory

In [14] community memories are defined as ICT resources that enable communities to record and archive information relevant to the management of a commons. In our NoiseTube platform the community memory is a piece of software[2] which operates on a central Web-server and collects and post-processes all gathered noise pollution measurements and runs a website [1] which lets users explore, visualise, analyse and search through the data.

The main post-processing features are:

Automatic contextual tagging: to complement the efforts of users additional tags describing different contextual dimensions such as time and location are added (e.g. "afternoon", "weekend", "Brussels", "Avenue Louise").

GPS correction: to partially make up for GPS positioning errors we apply a *map matching* algorithm. By making the assumption that all outdoor measurements are made in streets (i.e. not on roofs, in gardens or parks) and relying on a GIS database which stores digital street maps [3] the algorithm basically "pulls" all points that do not lie on a street to the nearest position that does.

The main user features are:

User profile (*Elog*): after post-processing, measurement sessions (or *tracks*) are added to the board of activity of the user, called the *Elog*, or "Exposure Log". Tracks also can be visualised on a map using Google Earth[4].

Collective exposure maps: Per city a collective noise map is available which shows all shared measurements made in that particular place. To add context and meaning to

[2]Built with Ruby on Rails and using a PostgreSQL database with PostGIS spatial extension in the back-end.

[3]Using data provided by authorities or obtained through free services like OpenStreetMap (http://openstreetmap.org).

[4]Google Earth is available for free at http://earth.google.com.

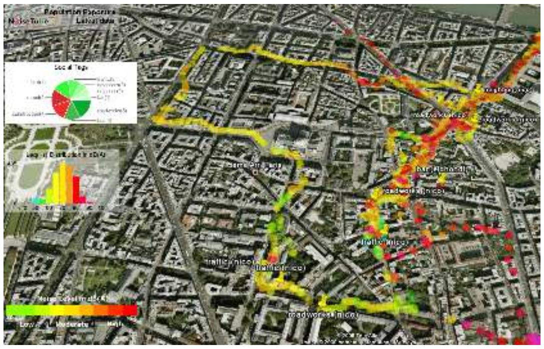

Figure 2. Collective noise map for part of Paris, France

the data, the maps include a semantic layer (consisting of the social tags) and legends. Figure 2 shows an example.

USAGE SCENARIOS

Since about 12 months anyone can download the NoiseTube mobile application to start contributing noise measurements to the community memory. So far over 500 people from over 400 places around the world have done this. However, for the most part these efforts have remained too (spatio-temporally) distributed and short in time to generate useful noise maps. To some extent this is due to stability issues (it's a *beta* after all), but the main reason is a lack of (local) coordination and features to support such initiatives. We see a number of scenarios in which coordination among a group of contributors could come about. In an effort to categorise the possibilities we differentiate them according to the party who takes the initiative.

Citizen-led initiatives

Because of the low barrier, in terms of both cost and complexity, concerned individuals can use the platform to study noise pollution in their neighbourhood. The participants can be self-organised citizens with varying levels of organisational involvement: ranging from total strangers that happen to live in the same area; over loosely organised groups of neighbours facing a shared problem; to well-organised previously existing activism groups.

The motivation for such initiatives can be diverse: from curiosity about one's daily environment to the gathering of evidence on concrete local issues. These can be long-term issues (such as the problems faced by people living close to airports, highways, factories or nightclubs); short-term ones (such as roadworks or nearby construction sites); or accidental annoyances (such as manifestations). NoiseTube can be applied by citizens to complement (e.g. in terms of spatial and temporal granularity) the work of authorities or it can be used in places that are not covered by any official initiative. Examples of the latter case can be cities in developing countries.

Authority-led initiatives

NoiseTube can also be used by authorities and public institutions – typically, but not exclusively, on a municipal or regional level – to gather data on noise exposure and pollution. This data can be used to support decision and policy making in different domains such as public health, urban planning, environmental protection and mobility. Applying a system like NoiseTube can complement or be integrated with existing (traditional) environmental monitoring initiatives. However, the low cost of deployment also enables authorities that currently have no monitoring system in place due to limited budgets (e.g. small cities or authorities in developing countries) to start gathering data on the pollution their citizens are exposed to. When used alongside an existing monitoring system a participatory sensing platform could make up for missing data, help to estimate error margins of simulation models, add semantics (e.g. identification of pollution sources), etc.

Of course deploying a participatory sensing network on a wide scale requires a large number of participants. While authorities can choose to work exclusively with volunteers (i.e. concerned citizens), it may take big publicity, communication and coaching efforts to keep these people motivated and active. It is probably wise to look for schemes that provide (financial or other) incentives to contributors. A possibility could be to offer free calling minutes in return for measurement data or a leasing system in which volunteers are given a fancy phone that they can come to own if they remain active during a predefined period of time. Other schemes could involve publicity deals with advertisers or network operators.

VALIDATION

Over the course of this summer we are in the process of validating our system on two fronts.

On the one hand we have done laboratory work to improve the accuracy of the sound measuring algorithm. We now have access to an anechoic chamber and more sophisticated equipment then before [10] which allows us to come up with a more accurate calibration and a better estimation of the resulting accuracy for varying intensities and frequencies.

On the other hand we are carrying out a real-world experiment which simulates a coordinated noise mapping effort. Over the course of 2 weeks a group of previously untrained citizens (members of a community activism group in Antwerp, Belgium) are using the NoiseTube system to assess noise in their neighbourhood. We have provided them coaching and clear instructions on how, where and when to measure and for how long. The goal is to concentrate and coordinate efforts to obtain sufficient data to create a noise map that can be compared with official (simulation-based) noise maps of the area. This should allow us to assess the quality of data that can be achieved in optimal (strictly coordinated) conditions. By asking the participants to write a report and fill out a questionnaire we also hope to learn more about what they expect from crowdsourcing applications and which improvements they think can be made.

Upon writing this paper we are still processing the results of this experiment but we expect to have preliminary results by the end of the summer.

CONCLUSION: CHALLENGES & FUTURE WORK

We still face many unresolved challenges. A selection:

Usability issues: unfortunately the use of a phone as a noise level meter conflicts somewhat with the normal usage of the device. Measuring noise is pointless when the phone is put in a pocket or purse or when a telephone call is being made. To some extent this can be alleviated by pausing the measuring process when such an event is detected (e.g. using a light sensor in the first case). However, users may still find it impractical to use NoiseTube on their personal phone for long periods of time.

Need for a coordination subsystem: coordinating larger mapping campaigns with less strict instructions (to give users more freedom over where and when they measure) is almost impossible without a semi-autonomous system that can help initiative takers. Such a system could analyse the mobility patterns of users to send out route suggestions to fill coverage gaps or avoid double work.

Quality control & trust: because we are dealing with measuring devices of varying accuracy and users with varying levels of discipline and commitment (some may even try to bias results) the biggest challenge for ubiquitous crowdsourcing will be to come up with ways to filter out faulty values, estimate accuracy, detect and encourage expert contributors, etc.

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