SoundOfTheCity - Continuous Noise Monitoring for a Healthy City

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***Abstract*—Noise pollution is among the leading causes for illness among urban residents. It constitutes a major cause for stress and poor sleep, it reduces life quality while increasing the risk for hypertension, hearing loss and lower cognitive performance. In light of those risks, the European Union mandates the creation of noise contour maps to gather information about the exposure. Those maps however often lack enough granularity to cover all areas of the city and omit large areas from the map. Hence, the public benefit from the provided information remains limited.**

We present *SoundOfTheCity*, a project with which we endeavour to put noise measurement into the hand of the citizen. To that end we developed a smart phone application that allows the users to continuously measure the loudness of their environment. The measured data are anonymised and send to a central server where all generated information from voluntary participants on a city scale are aggregated and mapped to a meaningful noise visualisation map. Moreover, the application allows for uploading sound samples, captured from the environment, as well as providing each user with information on their personal exposure to noise.

Extrapolating from the current state of such participatory ambient pollution monitoring for health, we propose several questions on the future of such applications. We discuss how such systems may utilize more then just information on the distribution of pollutants, to make health monitoring more relatable to the monitored community.

***Keywords*-Noise measurement, User interfaces, Public healthcare**

I. Introduction

The modern environment confronts us with noise emitters almost constantly. Studies have linked noise exposure to a decline in health and in quality of life, citing raised blood pressure, hearing loss, decreased cognitive functions, annoyance and even psychological symptoms as possible effects [21].

In a strategy to avoid these effects, the European Union has issued Directive 2002/49/EC, the Environmental Noise Directive (END), that mandates all member states to monitor the problem of environmental noise pollution. The directive also decrees that local problems of noise pollution are to be addressed, a long term strategy to reduce the number of people affected by noise must be developed and that the public is to be informed of the pollution level [8]. Other states such as Japan and the USA have adopted similar regulations [1], [9].

Emerging from the aforementioned mandate, noise maps are created to establish a comparable collection of information on the burden put on society by noise pollution. However, these noise maps only cover major sources of noise, defined as "road and rail vehicles and infrastructure, aircraft, outdoor and industrial equipment and mobile machinery" (Article 5, Directive 2002/49/EC). Meaning, that most streets with less than three million cars per year are not considered on the map, as they are not perceived to be major sources of noise. It should additionally be noted, that these maps are based on calculated not on measured noise exposure.

People who live or work in areas that are not close to major sources of noise are nonetheless faced with noise during their day. Such exposure cannot be measured in detail by government agencies, as it would, in addition to putting unreasonable financial strain on such agencies, be a gross infringement on the privacy of those citizens. In light of the discrepancy between the need for detailed information on the noise exposure in a community and the given limits of the government's efforts, the concept of participatory sensing presents a fitting solution. Participatory Sensing is the use of sensor technology by the citizens to "gather, analyse and share local knowledge" [4] using commercially available sensor technologies. While just ten years ago such efforts would have seemed unrealistic to attempt with the general public, the spread of mobile phones has endowed most people with a capable sensor platform in their pocket.

The remainder of this paper presents *SoundOfTheCity*, focusing in section 2 on related work on participatory sensing specifically in the area of noise pollution. Section 3 introduces the concept and design of the application. In section 4 we discuss how participatory sensing of such environmental pollutions as noise may change the landscape of community health followed by the conclusion.

II. Related Work

At the end of 2011 around 6 billion people, 87% of the world's population, had a mobile phone subscription (according to http://mobithinking.com). While in that year only 31% of sold phones where smart phones, the market

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Comparison Criteria	Personal Exposure	Community Exposure	Risk Assessment	Experience Capture	Continuity	Energy-Awarness	Correctness	Unobtrusiveness	Context-Awareness
SoundOfTheCity	★	★	★	★	★	○	(grey)	★	★
NoiseTube	★	★	★		○		★		
Noise Spy	★	★			○	○	★	(grey)	
Ear-Phone	★	★			★		★	★	○
WideNoise	★	★					(grey)		
MobGeoSen	★			★	(grey)		(grey)	(grey)	

Figure 1. Features for ambient pollution monitoring applications for health. Using nine criteria derived from literature and our analysis we compare the features of similar applications. A star defines fulfilment, a circle denotes partial fulfilment or unimplemented concepts. A grey field denotes that we have no conclusive information. The assessment is based on [11], [12], [15] and [18] as well as using the apps and web-services where available.

share for smart phones is rising. Already 700 million mobile phone users use a smart phone.

The mobile phone has become a personal and permanent companion. As such, mobile phones are increasingly adopted as a suitable platform for personal health monitoring in our daily environment. It has been used to monitor and share personal step count [5], sleep quality [14], social interaction [6] or other parameters.

Not just personal vital parameters are sensed in the guise of ambient health monitoring. Environmental data directly influences the health of the population. Several projects have envisioned mobile phones sensing potentially harmful environmental conditions in the environment of their owners.

Since air quality levels can usually not be measured by the internal sensors of commodity mobile phones, additional modules are attached to the phones to undertake air quality monitoring. In this case the mobile phone serves as controller and gateway, controlling the sensors, collecting the data and sending it wirelessly to servers.

Eisenmann and colleages [7] measured air quality as one of many values to provide health sensitive routing for bikers. Honicky et al. [10] developed additional sensors to measure air pollutants that where connected to phones to map air pollution and other sensed data. Kanyo et al. [12] developed MobGeoSen, a mobile phone based system that utilizes different sensors to measure environmental pollution like carbon monoxide level. The app also allows to upload pictures of the places related to the data. Pictures and measurement from a user are displayed using Google Earth.

Amini et al. [3] describe the development and validation of a wireless, portable and inexpensive sensor to measure exposure to UV-rays. Based on the measurement results, users are guided to reduce their sun exposure below the recommended time. The mobile application can be personalized to consider skin type and the use of sunscreen. Other projects, such as in [13], utilize the use of mobile phone camera sensors to register radioactive particles as a Geiger counter application.

Previous works, including [12], have considered the mobile phone as a platform to chronicle noise exposure. Since all mobile phones are equipped with a microphone, these projects do not suffer from the need to use additional sensors.

NoiseTube [15] is a system comprised of a mobile phone application and a web portal. The application allows to initialize noise measurements and record these to the website to be downloaded and viewed on Google Earth. NoiseTube additionally provides users with a noise exposure dosimeter that informs the user of his daily dose of noise pollution.

Noise Spy [11] is described as a "low cost data logger for monitoring environmental noise". Noise Spy also enables the user to assess his personal exposure level. However the purpose of this study was to demonstrate that mobile phone sensing can be done at a city level as well as that dynamic user generated noise map could be provided while still maintaining the single users anonymity.

Ear-Phone [18] is an "end-to-end participatory urban noise mapping system" that also uses the phones microphone to determine noise level and send geo-tagged data to a server to be analysed and mapped. This project improved on city-scale noise maps using the Australian acoustic standard, which allows adjacent measured areas to only differ by 5dB. Thus, an approximation of missing data is developed and evaluated.

WideNoise [2] is an application with similar features, available for Android and iPhone. The mobile phone application allows for user initiated noise level measuring. The measurements are reported to the server and displayed on a map. Additionally, WideNoise offers users to post measurements on facebook or twitter to raise awareness.

From reviewing the related work we developed nine criteria (figure 1) for ambient health applications measuring environmental pollution. The last four criteria are taken from [19]. These criteria present a guiding principle to design comprehensive ambient pollution monitoring application for health and are defined as follows:

R 1. Personal Exposure. Visualisation of the recorded sensor values could be used to provide the user with information on their level of exposure. This information must cover aggregated historical data as well as current data.

R 2. Community Exposure. Environmental pollution always affects communities, not just individuals. Therefore, a representation of the exposure in the community has to be found and related to the users.

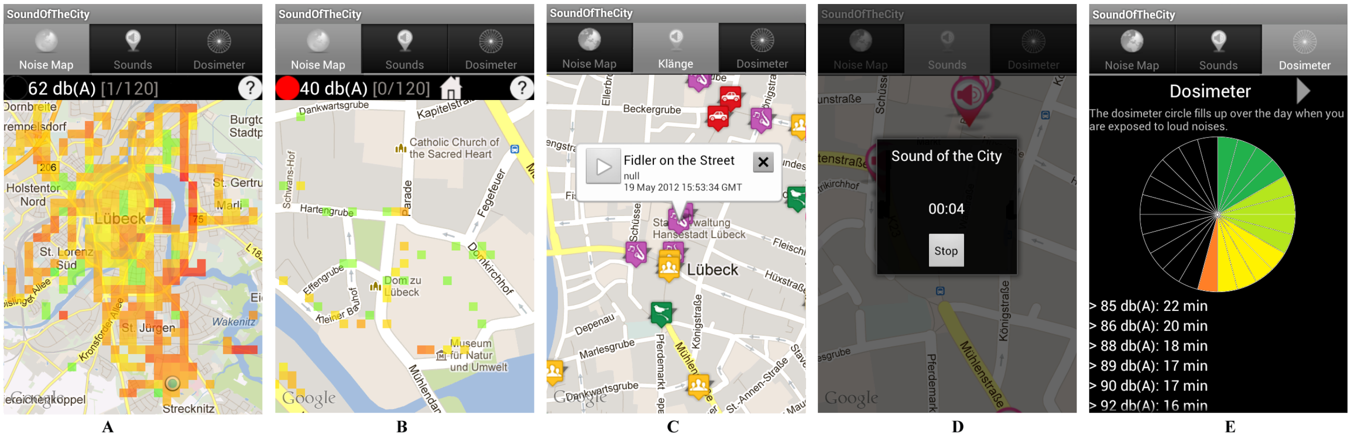

Figure 2. *SoundOfTheCity* mobile application. A. The main tab offers a geo-visualisation of the noise exposure in an area. B. Users can zoom into the map to get higher resolution C. The sound map shows the location of recorded samples. D. Users can use the software to record sound samples. E. The personal noise exposure over a day period is shown using a dosimeter metaphor.

R 3. Risk Assessment. Based on exposure data, the system must asses the health risk to the user and relate this information. While such information can not replace the advice of professionals it may offer a guide to the user.

R 4. Experience Capture. Measuring allows for data on the extend of exposure but does not represent the experience of those exposed. Applications that work with environmental exposure should strive to allow users to capture their experience, be it in sound, picture or other media.

R 5. Continuity. In assessing the heath risk to person and community, measuring has to be continuously performed by the application to allow for sufficient data.

R 6. Energy-Awareness. Since mobile devices are used for more then exposure measurement and users heavily depend on their devices, any ambient health application needs to be energy-aware and minimize its impact.

R 7. Correctness. To base health assessment and exposure assessment on measured data, the correctness of data must confine to defined regulations or boundaries.

R 8. Unobtrusiveness. The system should access resources in the background without requiring the user to perform an interaction to participate in the task of sensing.

R 9. Context-Awareness. Information on the context of the device and the users should be collected to trigger, change or stop measurement.

III. SoundOfTheCity

Finding the quiet places for a walk, searching for the lively places in a foreign city, calling the government to action in providing help against noise pollution or just reducing one's own exposure by becoming conscious of the extend: all these are scenarios that require an easy way to measure noise as a community and share the data.

With such features in mind, *SoundOfTheCity* adopts a participatory sensing approach to measure the noise levels on a city scale to draw and generate general noise maps for the city supporting various medical health monitoring purposes.

The project currently offers two types of user participation, i.e., active participation and public awareness participation. Users can actively participate by turning their mobile phones into noise measurement devices by downloading the *SoundOfTheCity* application. The application offers an assessment of the personal exposure and allows users to upload recorded sounds to provide a description of their experience. The app allows for continuous, context-aware and unobtrusive noise measuring. The app is divided in three main tabs, shown in figure 2. The app also offers some settings. Users are informed about new versions and project updates with an integrated news feature.

Public awareness participation is facilitated through the web portal[1]. The portal provides the general public with interactive noise and sound maps to access the collected city-scale data.

In the following sections we describe the features and their realisation in detail and refer to the nine criteria when appropriate.

A. Architecture

SoundOfTheCity has been developed as a client-server architecture (figure 3), with the Client running on smart phones using the Android operating system. The *SoundOfTheCity*-Server consists of four main modules:

Data input gate. This module is responsible for receiving all data reporting and access requests. The module implements an extensible SOAP interface (Simple Object Access Protocol) to allow mobile and web clients for accessing the available data.

Media streaming and encoding module. SoundOfTheCity hosts a RED5 streaming server to stream the captured sound

[1]http://citysound.itm.uni-luebeck.de

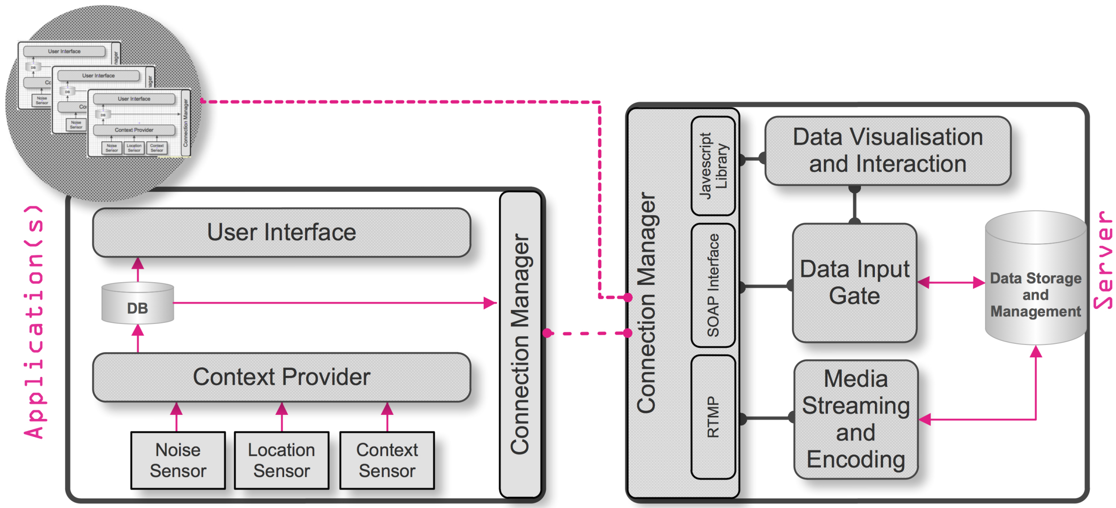

Figure 3. ***SoundOfTheCity* Architecture.** The client uses different sensors to asses its context. Noise samples are first stored locally before they are send to the server. On the server side a data input gate receives the data. Sound samples are processed in the encoding module before storage. A visualisation module handles the display of data to the web.

samples to the requesting clients using the RTMP protocol (Real Time Messaging Protocol). Unlike pure downloading, real-time streaming enables adaptation to the set of client capabilities. Moreover, this module contains a media encoder to ensure media sound samples uploaded to the server are correctly encoded to avoid heterogeneity problems resulting from the reporting mobile devices.

Data visualisation and interaction module. This module is responsible for aggregating the available noise measurements data into meaningful visualisation and allowing user interaction with the interactive maps provided. The visualisation and interaction are facilitated through the *SoundOfTheCity* Javascript library.

Data storage and management module. This is responsible for storing and managing the data on the server. The project currently use MySql database for data storage. The module is responsible for aggregating and querying the database based on geo-information.

The *SoundOfTheCity* mobile client relies on a central *ContextProvider* module that coordinates the use of sensors like noise measuring or GPS. Received noise measurements are tagged with geo-location and stored in the SQLite-database to be later uploaded to the server.

Some data is stored locally, like data on personal exposure or sound samples that have not been uploaded yet, other data is provided through the server API, like the noise distribution in the environment. The UI-components display both local and remote data combined to the user.

B. Noise Measurement

Noise measurements are by default performed every 30 seconds for one second. The algorithm uses the Android-API to access the amplitude of a recorded sample.

While *SoundOfTheCity* endeavours to provide continuous sampling of noise levels, there are situations in which the data cannot be deemed reliable enough to be of use for the community. With mobile phones as the platform, this applies especially when the device is in the pocket of a user. It also applies when the user is indoors or travelling in a car or train. *SoundOfTheCity* uses several sensors to provide context-awareness (*R9*). Measurements are not send to the Server when the user is believed to be indoors (using GPS and Wi-Fi-Signals), moving at high speeds (determined via GPS) or if the phone is in the users pocket (proximity sensor).

Sensing is performed in regular intervals by *SoundOfTheCity*, regardless of the situation. If applicable, the data is send to the Server, otherwise it is only used to asses personal exposure, since it most closely reflects the user exposition to noise but is of no use to the community (*R5*).

The application is unobtrusive in that it requires no configuration or handling once started, but allows to turn measurements on and off at the user's convenience (*R8*).

In performing noise measurements with mobile phone microphones we attempt to reach a satisfying level of correctness. This is necessary to provide the users and a community with a benefit. *SoundOfTheCity*s algorithm has been continually improved and while an evaluation is ongoing the first results are promising (*R7*). Currently work is ongoing to determine the characteristics of mobile phone microphones and to develop noise-measurement algorithms that specifically take those characteristics into account.

The use of multiple sensors, among them GPS, and the continuous performance of noise level measurements can constitute a strain on the mobile phone battery. With the aim of providing users with an unobtrusive experience, an

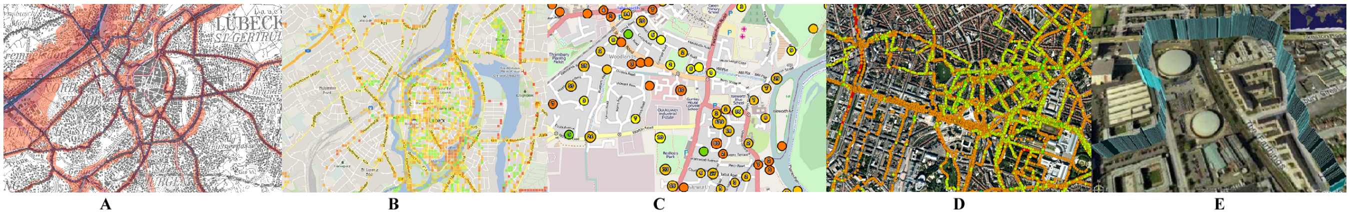

Figure 4. Different visualisations of geo-located noise levels. A: 2012 State mandated noise map of an area of Lübeck, covering only the main noise sources, like major traffic routes [20]. B: *SoundOfTheCity* noise level map, displaying noise level from green to red squares according to the averaged noise level [22]. C: WideNoise map of a part of London, showing circles from green to red according to averaged loudness, the size and number elude to the number of samples collected [2]. D: NoiseTube visualisation with Google Earth of Brussels, each dot presents a single measurement overlaid with each other.[17]. E: MobGeoSen visualisation on Google Earth. The hight of the lines responds to the noise at a given place [12].

acceptable battery life time has to be possible even with the application running. So far, *SoundOfTheCity* supports specifying the measurement intervals and the usage of GPS in order to reduce energy consumptions (*R6*).

For future versions we plan to incorporate energy-awareness by observing the battery state and automatically adjust the software's behaviour accordingly.

C. Visualisation

As shown in figure 2, *SoundOfTheCity* offers three different visualisations. The first shows the exposure to noise in a given, locally defined, community (*R2*a). This visualisation is identical in the mobile and the browser based version. According to [18] squares are a recommended style of visualisation for noise measurements. *SoundOfTheCity* uses squares of dynamic size to visualise the noise map, but as shown in figure 4 other visualisations have been proposed by other projects.

Users can change the zoom factor of the map, resulting in hierarchical increased sampling resolution. We are currently working on extending this with options to define sliding windows and progress animations. This would allow to browse through the sound map like common in weather radar maps.

The color of the squares varies depending on the average noise level measured inside the area covered by the square. The color ranges from green (less then 40 dB(A)), over yellow and orange to a deep red (more then 90 dB(A)). Currently, the map only provides a long-term average visualisation which is constantly updated with new incoming measurements.

SoundOfTheCity also offers visualisation of the personal noise exposure. At any time users can see the current noise level they are exposed to (*R1*). Using the metaphor of a dosimeter, a circle fills up, signalling the amount of noise compared to guidelines by the National Institute for Occupational Safety and Health [16]. This dosimeter is reset daily. If the recommended limit is surpassed, *SoundOfTheCity* will send a notification to the user advising him on the status (*R3*).

D. Experience of Exposure

Measuring the exposure to environmental pollution results in useful data but does not offer the possibility of relating the experience of being exposed to the pollution. Giving users the opportunity to express their feelings and experiences allows for more context and better understanding of the pollution.

Noise is perceived subjectively based on the social circumstances and by no means is every noise interpreted as a bad experience or an annoyance. Parties, concerts and other social events are noisy but welcomed by their participants.

WideNoise [2] acknowledges this by allowing people to tag a recorded sample and rate it in terms of "love vs. hate", "calm vs. hectic", and others. NoiseTube [15] also allows for tagging. Users can choose tags freely, allowing them to express their subjective opinion.

While detailing such information on every sample taken is irreconcilable with the notion of an unobtrusive sensing application the experience of noise has to be considered.

SoundOfTheCity allows users to record sound samples (see figure 2D), tagged with geo-location and time as well as a description to relate the experience of sounds at places (*R4*). These sound samples can be listened to using the website or the mobile platform (figure 2C).

IV. Conclusions and Future Work

SoundOfTheCity enables users to continuously measure their exposure to noise and make the geo-located data available to their community. In the first 5 months of deployment 183,256 ”noise measurements have been gathered. *SoundOfTheCity* application has been downloaded 362 times and the *SoundOfTheCity* portal viewed by more than 1200 visitors according to Google Analytics.

SoundOfTheCity is designed as an ambient health monitoring application assessing not just the personal exposure to noise pollution but also the exposure of communities. We proposed nine criteria for exposure related health applications which guided our development of this new system.

While several mobile solutions for measuring noise level have been explored in the literature, *SoundOfTheCity* provides a less obtrusive handling, more complex context detection, continuous sampling, proactive health risk assessment and a visualisation that is not just fast and easy to understand but also conforms to proposed style recommendations.

We allow users to tag sound samples. To annotate these samples users are able to categorise with a fixed set of tags in concordance with the classification of noise by cause. These typically include “road traffic”, “train traffic”, “air traffic”, “construction”, and others.

Such tagging may allow future versions of *SoundOfTheCity* to visualise not just depending on the loudness on certain places but also include information on possible sources of noise. This may spark vibrant discussions in the community to develop strategies to reduce the noise level. Knowing the types of sources may provide for a fact based discussion.

In a collaborative project with several institutions within the city of Lübeck we aspire to help citizens find and define the most pleasant sites in the city, using a combination of questionnaires and noise measurements. We hope to be able to provide not just a location based view of the objective loudness but also of the subjective opinion towards the noises.

V. Acknowledgements

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