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Participatory noise mapping works! An evaluation of participatory sensing as an alternative to standard techniques for environmental monitoring

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ABSTRACT

Participatory sensing enables a person-centric collection of environmental measurement data with, in principle, high granularity in space and time. In this paper we provide concrete proof that participatory techniques, when implemented properly, can achieve the same accuracy as standard noise mapping techniques. We do this through a citizen science experiment for noise mapping a 1 km^2 area in the city of Antwerp using NoiseTube, a participatory sensing framework for monitoring ambient noise. At the technical side, we set up measuring equipment in accordance with official norms insofar as they apply, also carrying out extensive calibration experiments. At the citizen side, we collaborated with up to 13 volunteers from a citizen-led Antwerp-based action group. From the data gathered we construct purely measurement-based noise maps of the target area with error margins comparable to those of official simulation-based noise maps. We also report on a survey evaluating NoiseTube, as a system for participative grassroots noise mapping campaigns, from the user perspective.

1. Introduction

Pervasive computing naturally lends itself to many of environmental sustainability's core challenges. For one thing, it provides numerous possibilities for better monitoring the physical world [1], by way of miniaturised sensors which are becoming ever more pervasive, performant and cheap. At the same time pervasive technologies are inherently connected to their users, which means that they can play an important role in awareness building. The realisation that pervasive technology can provide a direct link between data and people has crystallised into the idea of *participatory sensing*, which appropriates everyday mobile devices such as cellular phones to form interactive sensor networks that enable public and professional users to gather, analyse and share local knowledge [2,3]. Its potential for data collection at a high granularity in space and time, very difficult for scientists to achieve otherwise, together with its potential for citizen involvement at all layers of society, make this an extremely promising tool for monitoring and managing the environment [4,5]. One particularly interesting application of these ideas is to construct participatory, measurement-based environmental maps. Indeed, while there are already important efforts going on to monitor the effects of pollution, these are mostly in terms of computer models and urban statistics, while very little actual measuring is involved. The resulting maps give an average but not at all a complete view on the situation, entirely missing local variations. Crowdsourcing through participatory sensing

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techniques alleviates these issues and allows for a person-centric approach to gathering and visualising actual data on a much larger scale.

Any successful participatory sensing application lies at the nexus of three essential ingredients: *technology*, *data* and *people*. For environmental monitoring the data aspect is of particular importance. Indeed, already today there is much demand from citizens, activist groups and even city administrations for using participatory technologies to tackle local pollution issues.[1] Of course this has only been possible because the underlying technologies have been much publicized, in academic literature [6,7] but also in the media. However, it is an open question whether the data gathered with these technologies is at all accurate. This is crucial to the cause of anybody wishing to set up environmental monitoring actions, as inaccurate data would not only affect the action involved but also the success and credibility of any future actions. The issue is especially sensitive because authorities often assume, out of convenience or out of conviction, that data collected by citizens by means of participatory sensing techniques are not nearly as accurate as data gathered by officials using conventional assessment methods. This article focuses on determining what exactly the data quality is that one can achieve, given a concrete case (noise), an operational participatory sensing system (NoiseTube), and an actual measurement campaign designed with these issues in mind. We pay special attention to standards, norms and conventional noise assessment methods, with the aim of giving a first qualitative comparison between the existing and proposed approaches. We stress that our current focus is not on the technology, nor on large-scale deployment, which do not make sense before the issue of data quality is settled.

We choose noise as a concrete case for several reasons. First, noise pollution is representative both in that it is tightly correlated to other types of pollution and in terms of the structure of the regulatory framework behind it. Second, it is a very actual topic of concern for citizens and authorities, and indeed there are currently important efforts going on to monitor its extent and assess its effects [8,9]. Third, there has been considerable progress in technologies for participatory noise monitoring, with applications such as EarPhone [10], NoiseSPY [11], WideNoise and our in-house NoiseTube application [7,12] taking the lead. Our choice for working with NoiseTube is motivated not only by pragmatic reasons but also because as the only open-source, publicly available project, targeting several platforms and involving not only a mobile application but also a web-based community platform, we feel it is the most complete solution to date [12]. Tried and tested on an individual-user level, it allows us to focus on the data quality aspect rather than on the technology.

The structure of this paper is as follows. We first give an overview of what official noise pollution norms and assessment techniques encompass in Section 2. In Section 3 we set up our measuring equipment according to these norms, and report on extensive calibration experiments and subsequent testing of our equipment, in and outside the lab. This section already provides half of the work towards profiling participatory sensing data quality, as it thoroughly improves the accuracy of mobile phones as sound level[2] meters (by correcting for systematic errors), while also assessing their precision as stand-alone devices (by evaluating the spread of random errors). Next we report on the various implementation steps for a 2-phase realistic citizen science experiment for noise mapping a 1 km^2 area, and analyse the resulting maps. To do this we collaborated with 13 volunteers from a citizen-led activism group, equipping each of them with a mobile phone for measuring and allowing extensive feedback sessions on results, experiences and usability. This coordinated mapping campaign allows us to answer the other half of the question on data quality, namely whether large datasets can make up for the inferior accuracy of mobile phones with respect to professionally used equipment. The outcome of our experiment is a set of purely measurement-based, statistically analysed noise maps of the target area, comparable to official noise maps in terms of data quality. We also include a qualitative comparison with the latter, highlighting similar patterns as well as differences and arguing how these underline the credibility of our approach. Although participatory noise maps have been reported earlier in literature [10,11], they are either much more limited in scale or they do not take the data quality aspect nearly as serious as we do in the work presented here. Finally, because adoption by the wider public is so important for participatory techniques to take off, we organised a user survey of which results are presented in Section 5. While the group is too small to draw any kind of general conclusion, the feedback gathered is still extremely useful to fine-tune future experiments. To conclude, we discuss the validity and value of participatory noise maps in Section 6, where we also provide general guidelines on noise mapping protocols and report on our experience with extending the participatory approach to the level of large-scale adoption.

2. Noise mapping today

The European Union is at the forefront when it comes to noise assessment [13]. Indeed, there has been a tradition in noise mapping for many years, at least at the level of individual member states. On the basis of this tradition European-wide regulations were defined in the form of European Union Directive 2002-49-EC [8]. This directive has in turn incited further developments in noise assessment methods, and has essentially led to an inventory of noise maps for large cities throughout Europe. The United States, though its Noise Control Act dates back to 1972, does not mandate noise mapping at a federal or

[1] This is obvious from our own experience, as we are regularly contacted by these actors for setting up actions, and from the success of organisations such as Mapping for Change and the Public Laboratory for Open Technology and Science (PLOTS).

[2] Sound level is the physical parameter measured, while noise, i.e. unwanted sound, is the term more commonly used in environmental assessment contexts.