Beyond boundaries: the home as city infrastructure for smart citizens

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Abstract
Low-cost sensing technologies that stream data into web platforms have become increasingly available for households, blurring the boundaries between the public and the private. In this paper we draw on our experience with the Smart Citizen crowdsensing project to present a vision of a future where households become city infrastructure through the data they produce. We highlight the challenges involved with this vision in the hope that they will contribute to both academic and industry discussions on the possibilities and difficulties around home-based crowdsensing technologies.

UbiComp'14 Adjunct, September 13-17, 2014, Seattle, WA, USA
ACM 978-1-4503-3047-3/14/09.
http://dx.doi.org/10.1145/2638728.2641557

Author Keywords
Crowdsensing; Internet of Things, Smart Cities, Home-based technologies

ACM Classification Keywords
H.5 Information Systems. H5.m. Miscellaneous.

Introduction
A plethora of low-cost sensors are becoming embedded in households, usually with the goal of gathering data both from inside the house, such as smoke and carbon monoxide levels [10]; and from the external environment, ranging from air quality to noise pollution and so on [4]. While some of these systems aim to help tenants manage resources efficiently or achieve more sustainable behaviours [5], others allow citizens to sense and share data to collectively monitor the environment. The latter are usually referred to as crowdsensing or community sensing technologies and are not intended to replace official monitoring stations, but rather augment the granularity of the monitoring network with distributed low-cost sensors [6]. Notable examples are the Air Quality Egg [1] and the Japanese Safecast and RadiationWatch, which were used by

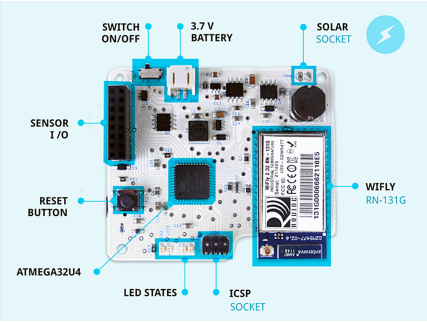

Figure 1. Interior of the Smart Citizen Kit board.

citizens to monitor radiation levels after the nuclear disaster at Fukushima Daiichi [8].

In this paper we present insights from an on-going ethnographic study around the Smart Citizen project, which uses open source technologies to enable citizens to capture and share environmental data. We propose that this type of home-based crowdsensing technology reveals the blurred boundaries between the public and the private domains, and highlights ways in which citizens might harness the potential of the Internet of Things to reconfigure their environment. An example of such empowerment is the Open Source Beehives project [11], where users are adapting sensors to be used in beehives to help protect bee populations in cities.

Nevertheless, to reach their potential home-based crowdsensing technologies need to be maintained and operated by citizens in a sustained manner. Our study reveals that sustained engagement is problematic and that these tools need to overcome a number of challenges associated with the robustness of the technology; troubleshooting advice; and reliability and meaningfulness of the data. We illustrate these tensions using preliminary findings from a case study analysing two Smart Citizen groups: The "early adopter" community, with over 100 users who backed the project via crowdfunding; and the Amsterdam community, consisting of 73 users and instigated in collaboration with The Waag Society, Amsterdam Smart City and the Amsterdam Economic Board. By highlighting these challenges we hope to contribute to discussions around the design and deployment of home-based sensing technologies.

The Smart Citizen Project

Smart Citizen comprises a sensor kit (SCK) and an online platform that enable collective sensing and sharing of environmental data. It was launched in 2012, instigated by the second author of this paper and a group of stakeholders [4]. The SCK, in figure 1, consists of an electronic board and shield based on Arduino; a WiFi antenna; and a set of sensors to monitor: humidity; temperature; nitrogen dioxide; carbon monoxide; sound pollution; solar radiation; and wavelength exposure. The kit can be deployed indoors or outdoors and consumes little power (complete description of the system in [4]).

Challenges

Over 600 SCKs have been logged in at least once, contributing more than 135 million data entries so far. However, less than 30% of these sensors are kept online. Our findings indicate that interest for crowdsensing tools comes mainly from males who care about technology. In our "early adopter group" only 28% were females and more than 85% of all users declared an interest in technology. The motivations underlying user engagement with the Smart Citizen project are: i. interest in exploring these kind of technologies; ii. interest in generating open data; and iii. desire to be part of a data gathering community. Despite these motivations, there are many issues that hinder sustained community engagement with Smart Citizen [3].

Technology set up and troubleshooting

Even though the technology is designed to be easy to set up, users find it difficult to log in the kit, for example: *"I haven't used the kit yet...and that is because I still don't have it online (…) because the*

process is too long, even if not difficult but still too many steps for the time I have available", and *"Even though I can't seem to set up my kit I continue really excited about the project"*. Users' opinions indicate that while they see value in Smart Citizen they expect the devices to be plug and play. Significant resources need to be assigned to provide assistance with troubleshooting and documentation that users can check online while setting up their devices at home by themselves.

Robustness, calibration and maintenance

Most low-cost sensors for environmental monitoring lack the robustness required to produce reliable data. In addition, keeping the sensors calibrated is crucial to obtaining reliable measures but a vast majority of users ignore the guidance for calibration. This leads to random readings that negatively impact the quality of the data. If users distrust the data they tend to disengage with the project, for example: *"I think that we are storing a lot of data, but this data have a great inaccuracy. For the moment, I would not use the kit in projects that needs some functionality"*.

Meaningfulness of data

Little is known about how citizens can make sense of the data they produce and how this may translate into real-world action [2]. While our users indicated that they struggle to make sense of most of the data sensed by SCKs, they have come to appreciate measures that they can easily understand, such us noise levels. A user in the Amsterdam community said: *"Sound measures are good. People in my neighbourhood rely on my sensor kit to monitor that. We could do visualizations of these data because finding silence is important for people and might define where they want to live"*. She also suggested that these data could help citizens put pressure on the government to better control how bars and cafes impact the quality of life in certain areas.

Too calm to be noticed

Although Home-based systems should be unobtrusive to be welcomed at home, they need to provide a meaningful experience that reminds users of their existence. Some participants have suggested that they would like to receive notifications both about the data being produced and the state of their sensors, for example: *"(…) enable an option in the web platform to send you an email if your kit is off-line. Because sometimes it needs to be rebooted so you don't receive feedback if it has been offline for a long time"*. Nevertheless, if the system will provide feedback about the data collected, we need to further study how these data may affect users. As one participant suggested: *"If there is nothing I can do about it, then I prefer not to know how bad the air in my street is".*

From Households to urban infrastructure

Home-based crowdsensing tools have the potential to transform private households, which are usually seen as consumers of services only, into city infrastructure by becoming distributed monitoring stations producing public data and operated by citizens. On the one hand, houses tend to have an Internet capacity that is under utilised and can be used to produce and share data for domestic private uses as well as for social collective purposes. On the other hand, unlike official sensing stations, citizen sensors are located at the human level, capturing data about phenomena in direct proximity.

Contrary to other home-base systems that collect data about private resource consumption, Smart Citizen

focuses on monitoring environmental data that can be used to map and predict phenomena at a neighbourhood scale. This attenuates the rise of privacy concerns (like those highlighted in the Google Nest parody [7]) and empowers citizens to tackle specific sustainability issues. An example of this form of empowerment is the Open Source Beehives (OSBH) initiative, which is currently appropriating SCKs as part of a collaborative response to the threat faced by bees in industrialised countries. They intend to design hives that can support bee colonies in a sustainable way, and to monitor and track their health as they develop [11].

However, home-based technologies need to overcome a number of challenges to be welcomed into the private space of the home, appreciated and maintained by tenants. The challenges faced by Smart Citizen correlate with those found in similar projects (e.g., [9]). We propose that improving the robustness of the technology; facilitating online peer assistance for troubleshooting; and focusing on communities of users with specific concerns (bee keeping, for example) might fuel sustained community engagement and help scale up crowdsensing projects.

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