Approaching a human-centred Internet of Things

Treffyn Lynch Koreshoff, Tuck Wah Leong, Toni Robertson
Interaction Design and Human Practice Lab
Faculty of Engineering and Information Technology
University of Technology, Sydney
{Treffyn.Koreshoff, TuckWah.Leong, Toni.Robertson}@uts.edu.au

ABSTRACT
This paper surveys recent Internet of Things (IoT) related HCI literature, and examines it in light of a comprehensive framework by Atzori et al. (2010). Mapping HCI literature to this framework helped us understand the extent and the focus of IoT related HCI efforts, including a lack of HCI engagement with deeper human-centred perspectives of the IoT. It also revealed HCI considerations for the IoT which we added to the framework. This extended the framework to a tool for an HCI audience that can be used for 'thinking through' the design of IoT technologies. We close the paper by demonstrating how this tool has been found useful in an IoT research project and at the same time illustrating our approach in how to engage more deeply with human-centred concerns.

Author Keywords
Internet of Things (IoT); Ubiquitous computing; Human-centred approach; Design; Framework;

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION

The Internet is changing from "a network of interconnected computers to a network of interconnected objects" (European Commission 2009). This extension of the Internet to include everyday objects, places and environments is referred to as the 'Internet of Things' (IoT). As such, the IoT's vision is to create the potential for people, objects and things of all kinds to communicate with one another via the Internet.

Many definitions of the IoT abound, but they mainly consist of highly technical terminologies identifying the IoT in terms of a network, services, infrastructure, protocol, and so on (EPOSS 2008, IoT-A http://www.iot-a.eu/public/terminology). Even when describing human concerns such as privacy and trust, these descriptions remain very technical, seeing them as technological hurdles to solve (Chen 2012; Romana et al. 2013). Issues such as how people could interact with these technologies, and how human agency is configured remain largely unaddressed. In other words, it appears that we currently lack a strong human-centred perspective on the IoT. Given this, we sought to find and/or develop resources that could help HCI researchers to think about and to engage more productively with human-centred design approaches for the emergent IoT. Our examination of IoT-related literature revealed a useful technical framework (originally proposed by Atzori et al. 2010) that we have modified and adapted. We believe this will allow HCI researchers to use the descriptive framework as a 'design tool' to think with when considering how to best approach, design and evaluate for the IoT.

UNDERSTANDING HCI EFFORTS WITH THE IOT

Atzori et al.'s framework is highly cited because it comprehensively describes the core technologies of the IoT and organises them within three broad categories of 'Things', 'Internet', and 'Semantic' (see figure 1). As such, this framework could be used to compare, map, and analyse IoT-related efforts within HCI to reveal the focus and extent of HCI's various engagements with the IoT. For example, how do particular efforts map to the categories? What categories have a particular HCI effort been focused upon? What are some of the differences of focus in HCI efforts when compared to this framework, and what are the gaps we can identify within current HCI efforts? In light of this, we will present Atzori et al.'s framework, and discuss HCI efforts surrounding the IoT. We will also illustrate how we have modified this framework to make it a design tool for HCI practitioners. Finally, we briefly describe how we used this design tool to think through a current IoT project, and how we could potentially address some of the gaps identified from this mapping exercise in order to ensure that it is human-centred. But first we will describe how we went about locating HCI-related literature of the IoT.

We began with keyword searches (e.g., Internet of Things, sensors, connectivity, etc.) and also searched the past four years' conference proceedings of CHI - the premier conference of HCI. Besides the sheer number of publications available annually from this conference, we also limited it to this time span because the IoT is still a relatively new research domain. Given that other research domains such as Ubiquitous, Tangible, Pervasive and Wearable Computing share considerable interests that overlap with the vision of the IoT (e.g., Reeves 2012; Ishii 2008; Satyanarayanan 2001; Reichl et al. 2007), we also surveyed this literature (using the same keyword searches). In total we examined 1,807 papers. However we only found 89 relevant papers. Next we discuss these papers using Atzori et al.'s framework but due to the space constraints of a short paper, we will only cite some of the most pertinent literature.

EXAMINING HCI-RELATED EFFORTS OF THE IOT

This section discusses Atzori et al.'s original framework and our modifications to it (Figure 1). When using this framework to dialogue with the HCI literature we surveyed, we saw opportunities to modify the framework to make it useful for an HCI audience. While we kept Atzori et al.'s original annotations (so that readers can still view the original framework), we moved the annotations into a grey box within each category. We then added a summary description of prominent HCI efforts within each category. As we will discuss later, this modification allowed us to view Atzori et al.'s descriptive framework of IoT technologies as a tool for thinking about the design and evaluation of IoT efforts from an HCI perspective. Next we introduce and discuss the seven categories of the framework, putting HCI efforts in dialogue with Atzori et al.'s original framework.

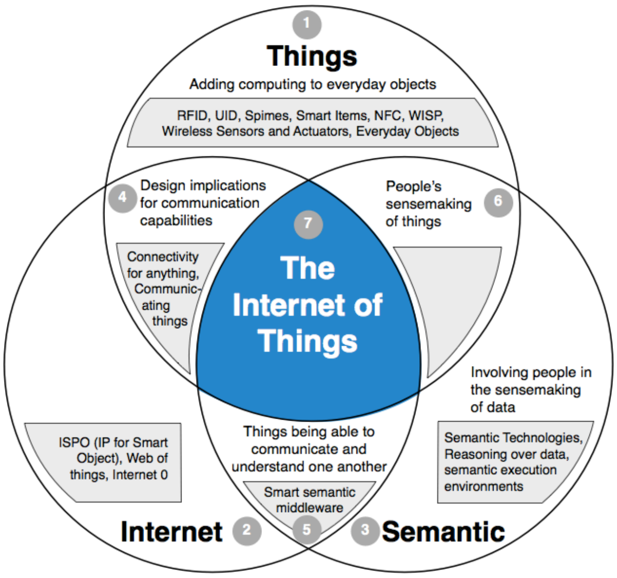

Figure 1: Modified version of Atzori et al.'s (2010) 'Internet of Things' paradigm.

1. Things. This category was used by Atzori et al. to refer to the physical components that would make up the IoT. That is, the sensors, actuators, technologies and objects that could be combined to create connected 'things'. The HCI literature we reviewed were generally less concerned with the particular components used, and more interested in considering *how* computing could be added to everyday objects, and what this can enable. We see this as '*adding computing to everyday objects*'. For example, strapping sensors to the skin to enable the human body to control computers (Harrison et al. 2010), or embedding different sensors into clothing to digitise and measure their use (Rantala et al. 2011).

2. Internet. This referred to the various languages and protocols that can be used when transferring data between 'things' and other objects on the Internet. In response to various efforts that tried to develop separate networks and protocols specifically for the IoT, Atzori et al. highlighted the advantages of using common Internet languages as the basis for communicating between objects in the IoT. The HCI literature we reviewed did not deal in depth with the kinds of protocols and languages used to communicate between objects. This perhaps reflects that such interests lie outside the scope of HCI.

3. Semantic. This category described the technologies to store, process and use data generated by the IoT. It referred to how semantic technologies could sort and begin to make meaning out of the potentially vast amount of information created by everyday objects which are beginning to sense and transmit data. HCI is only starting to engage with how technology could analyse and present the vast amount of data produced by connected objects (Davidoff et al. 2010). On the other hand, HCI researchers are increasingly aware that computers alone cannot clearly represent something as complex as human intention. This has resulted in a call for '*involving people in the sensemaking of data'* (Chau et al. 2011).

Three additional categories are formed in Atzori et al.'s framework by the overlaps between Internet, Things and Semantic.

4. Internet/Things. This overlapping category referred to the notion that all 'things' should have the ability to communicate via the Internet. This notion is also embraced by HCI efforts. In particular, we see this as '*design implications for communication capabilities*'. HCI is interested in how properties and limitations of connectivity might impact the way we design things for the IoT. For example, transmitting data over longer distances using wi-fi often requires physically larger devices due to power needs. Whereas smaller devices can be used for shorter transmissions because we can use low-power technologies such as near-field communication (NFC). To work around connectivity constraints, Nakatsuma and Shinoda (2010) propose a way for different computing parts, such as storage, processing and display, to network together simply by being placed on a desk. This opens up the exciting possibility of separating computers into different parts (e.g. display, storage, input etc.), which can then be combined together on demand via the Internet to be most suited to any given task.

5. Semantic/Internet. This category contains 'middleware', software that is designed to allow communication between 'things' by translating data to different formats. HCI literature appeared less concerned with how such connections are achieved technically, and more interested in the potential for '*things being able to communicate and understand one another*'. For example, Woo and Lim (2012) explore the possibility of an emergent "accidentally smart home environment", where new objects are added into the home one at a time. In this approach, they examine what would be needed to ensure the smooth addition of each new arrival.

6. Things/Semantic. This was only briefly discussed by Atzori et al. in regards to the need for scalable infrastructure to semantically process vast amounts of IoT data, and was not annotated in their original diagram. However, we found this area was well represented in HCI literature. Primarily, the efforts were centred around how data can affect *'people's sensemaking of things*', when everyday objects are embedded with computing. For example, how revealing usage data such as Internet bandwidth and water usage, can inform people's view of how they use that resource (Chetty et al. 2010; Froehlich et al. 2012). The secondary theme we found was around how objects react to new incoming information. For example, Odom et al. (2012) examine how different objects could store and display new digital photographs.

7. Internet of Things. For Atzori et al., it is the combination of technologies outlined in Fig. 1 that make up the IoT. On the other hand, our annotations reflect the different HCI considerations that need to be taken into account when designing for the IoT.

Discussing the modified framework

Overall this framework was effective in helping us understand the current IoT-related HCI efforts, and to interrogate them against a more technical framework and literature. Whilst we acknowledge that mapping HCI efforts to a primarily technical framework could be problematic, we found the HCI efforts mapped relatively easily to Atzori et al.'s original technical framework, reflecting that the HCI approaches around the IoT are still largely technical in focus. We found the majority of efforts focused around 'things', followed by 'semantic' and then the overlap between the two categories. The concentration of HCI efforts around 'things' perhaps reflects that this is an obvious starting point for the Internet of *things*. In addition, most of the efforts we surveyed came from the tangible and ubiquitous computing literature, both of which also work primarily with physical technologies. Using this framework led us to realise that while HCI efforts certainly considered the role of people within the IoT, e.g., how they make sense of the technology, they have not engaged in more human-centred issues. These include the consideration of human agency, and flexibility of use when multiple human interactions are occurring with multiple interconnected objects. This means the framework can only take us part of the way towards understanding how to design for a human-centred IoT. Nevertheless we found it a useful tool for 'thinking through' the various technical and HCI efforts in order to approach the design of IoT devices.

To summarise, this framework: 1) has helped us understand the extent and the focus of IoT related HCI efforts; 2) can be used as a tool for thinking through the HCI considerations that need to be taken into account when designing for the IoT; and 3) draws attention to the lack of engagement with deeper human-centred perspectives of the IoT.

Next, we will show how this tool can contribute to design, by demonstrating its utility in our own research that explores how IoT devices can help people age well in their homes. This case will also allow us to illustrate an approach for engaging more deeply with a human-centred perspective when designing for the IoT.

USING THE FRAMEWORK AS A TOOL FOR DESIGN

In designing IoT technologies to support ageing well, we used the framework as a way to 'think through' some of the design considerations. Starting from any category (refer to Fig. 1), and continuing in either direction, we used this framework to systematically check if and how we approached each of the HCI considerations. For example, starting at *Things* prompts us to first consider the objects in people's homes, and how we may embed computing into them. Whilst considering how technology can be added to particular objects, we are reminded that the ability of a particular object to communicate with others is limited by its physical properties (*Things/ Internet*). In our project, this meant a consideration of the size and weight of an object versus the desired range of communication, especially when used by the elderly.

Continuing counter-clockwise to *Internet*, we are faced with the need to select the protocols that will be used to transmit data to and from objects in our project. Whilst this category did not feature strongly in HCI literature, we believe it is still an important consideration. Our project opted for open web languages, such as HTML5, as this widens the potential for others to build on our work and allows for a greater range of devices to be used.

With *Internet/Semantic,* if the object we design is to fit in with the other objects already in the home, we need to consider how a new object can interface with existing objects (e.g. being able to understand each other). Having multiple objects around the home always on and transmitting sensory information, has the potential to create vast amounts of data. Thus the *Semantic* category prompts us to consider how that information, such as movement patterns in the home, could be analysed and presented. In addition, it reminds us to consider 'who' is responsible for the sensemaking of this data.

The final category in this framework is *Semantic/Things*. Here we considered how people understand and make sense of objects with embedded computing in them. For the elderly participants this entailed understanding how they expected one action, such as their movement into a new room of the home, should affect 'things' (e.g. turning lights on in the same room).

By stepping through a full circle of the diagram in this way, we have had the opportunity to think through how each of these HCI considerations could inform our design. This means that when we use this framework, we do more than simply add technology to objects, but also consider things such as the types of information the object would produce, and how people make sense of it.

However, as we mentioned earlier, this framework can only take us part of the way, in that additional efforts are required to ensure that people, their particular needs, contexts, situatedness and interests are firmly at the focus of an HCI approach to the IoT. In our project, we have tried to bridge this gap through using various design approaches such as Participatory Design. We chose Participatory Design because it has a commitment to co-designing with people, working closely with them to prototype technologies that are meaningful to them and technologies that are respectful of their skills and knowledge. Prototyping allowed people to engage actively in the sensemaking and understanding of data produced by IoT devices, and allowed them to decide and experiment with the parts of that data they found important to them. Participatory Design also has a commitment to facilitate mutual learning (Robertson & Simonsen 2013). Through this, we can get a better understanding of the person using the device, their priorities, their expectations, and the compromises they are willing to make (e.g., the tradeoff between the size of a *thing* and the battery life). At the same time our participants gain resources to support their abilities to envisage potential future IoT technologies.

We have used Hornecker and Buur's (2006) tangible interaction framework to better understand people's interactions with and through tangible technologies and to guide the design of prototype IoT technologies that can be used by ageing people in the increasingly hybrid physical and digital spaces of their own homes. The phenomenological commitments of the framework mean that its four themes and their related concepts can potentially be extended both to account for and inform the design of the interconnectivity between objects that defines the IoT.

CONCLUSION

In this short paper we have contributed a modified framework that can be used by HCI practitioners as a tool to think through designs for the IoT. Through mapping recent IoT literature to Atzori et al.'s original framework, we showed where IoT-related HCI efforts are concentrated, the types of technologies they considered, and the general focus of these efforts. From this mapping, we noted HCI considerations, which we added to the framework. This made the framework more useful to an HCI audience. In fact, we were able to use this as a design tool to guide our research project on the IoT.

Putting the concerns of HCI researchers in a dialogue with the more technical focus of Atzori et al.'s original framework highlighted the predominantly technical approach of much current IoT-related HCI research. There is both need and opportunity to develop understandings and design approaches that consider the deeper human-centred issues of the IoT. Existing human-centred design approaches, such as Participatory Design, and existing design tools, such as Hornecker and Buur's tangible interaction framework, can provide resources to develop a more human-centred focus for IoT design and development. Future research will include the application of Atzori et al.'s modified IoT framework to a wider variety of cases to both refine it further and to evaluate its contribution to this important endeavour.

REFERENCES

Atzori, L., Iera, A., & Morabito, G. The Internet of Things: a survey. Computer Networks, 54 (2010), 2787–2805.

Chen, Y. K. Challenges and opportunities of Internet of Things. Design Automation Conference, IEEE (2012), 383–388.

Chau, D. H., Kittur, A., Hong, J. I., & Faloutos, C. Apolo: making sense of large network data by combining rich user interaction and machine learning. In Proc CHI 2011, ACM Press (2011), 167-176.

Chetty, M., Banks, R., Harper, R., Regan, T., Sellen, A., Gkantsidis, C., Karagiannis, T., & Key, P. Who's hogging the bandwidth?: the consequences of revealing the invisible in the home. In Proc. CHI 2010, ACM Press (2010), 659-668.

Davidoff, S., Zimmerman, J., & Dey, A. K. How routine learners can support family coordination. In Proc. CHI 2010, ACM Press (2010), 2461-2470.

European Communities Commission (2009) Internet of Things — An action plan for Europe. http://eur-lex.europa.eu/LexUriServ/site/en/com/2009/com2009_0278en01.pdf (20/05/2013).

Froehlich, J., Findlater, L., Ostergren, M., Ramanathan, S., Peterson, J., Wragg, I., Larson, E., Fu, F., Mazhengmin, B., Patel, S. N., & Landay, J. The design and evaluation of prototype eco-feedback displays for fixture-level water usage data. In Proc. CHI 2012, ACM Press (2012), 2367-2376.

Harrison, C., Tan, D., & Morris, D. Skinput: appropriating the body as an input surface. In Proc. CHI 2010, ACM Press (2010), 453-462.

Hornecker, E., & Buur, J. Getting a grip on tangible interaction: a framework on physical space and social interaction. In Proc. CHI 2006, ACM Press (2006), 437-446.

Ishii, H. Tangible bits: beyond pixels. In Proc. TEI 2008, ACM Press (2008), p.xv-xxv.

Nakatsuma, K., & Shinoda, H. High accuracy position and orientation detection in two-dimensional communication network. In Proc. CHI, 2010, ACM Press (2010), 2297-2306.

Odom, W., Zimmerman, J., Forlizzi, J., Choi, H., Meier, S., & Park, A. Investigating the presence, form and behaviour of virtual possessions in the context of a teen bedroom. In Proc. CHI 2012, ACM Press (2012), 327-336.

Rantala, J., Hännikäinen, J., & Vanhala, J. Fiber optic sensors for wearable applications. Personal Ubiquitous Computing, 15 (2011), 85–96.

Reeves, S. Envisioning ubiquitous computing. In Proc. CHI 2012, ACM Press (2012), 1573-1582.

Reichl, P., Froehlich, P., Baillie, L., Schatz, R., & Dantcheva, A. The LiLiPUT prototype: a wearable lab environment for user tests of mobile telecommunication applications. In Proc. CHI 2007, ACM Press (2007), 1833-1838.

Robertson, T., & Simonsen, J. Participatory Design: an introduction. Routledge International Handbook of Participatory Design, Simonsen, J. & Robertson, T, Eds. Routledge (2013).

Romana, R., Zhoua, J., & Lopezb, J. On the features and challenges of security & privacy in distributed Internet of Things. Computer Networks, 10 (2013), 1016-1051.

Satyanarayanan, M. Pervasive computing: vision and challenges. Personal Communications, 8 (2001), 10-17.

Woo, J., & Lim, Y. Clipoid: an augmentable short-distance wireless toolkit for "accidentally smart home" environments. In Proc. CHI 2012, ACM Press (2012), 1751-1754.