‘I think they can hear us’: making sense of designing for sound in home IoT systems

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ABSTRACT
Sound has not yet been used abundantly in the design of home IoT systems. We want to find if there are opportunities for sound in home IoT, and to understand the emotional association of sound in a home IoT environment from a user perspective. We have created four different experiences to observe and discuss where the boundaries of acceptance and comfort lie when using sound as a means to convey communication in an home IoT system. The outcomes of this paper are meant to broaden the perspectives of designers on how to design sound for IoT systems.

KEY WORDS
Sound; Internet of Things; Designers; Computer Networks and Communications; Human-Computer Interaction; Data Sonification

INTRODUCTION
As a result of the growth of IoT (Internet of Things) systems more designers are designing for and with this relatively new system and its behaviour. An IoT system is a variety of (electronic) objects that are capable of communicating and interacting with each other to work towards common goals. [13]. Currently users are mainly being persuaded to interact through graphical user interfaces (see Toon [11], IFTT [12]) while the usage of sound within home IoT systems is still minimal. We do not mean sound as in speech, like the speech IoT interfaces Google Home [9] and Amazon Echo [10], but rather sounds that can be perceived as everyday listening [14] (More about everyday listening is described in the Related Works section of this paper). The field of sound in home IoT is worth exploring according to us because sound provides ways of interaction that graphical and tangible interfaces do not. Sound can be perceived by users from different locations simultaneously and be informed of multiple qualities such as size, speed, material, etc. [14], while looking at different screen interfaces at the same time is harder. Furthermore sound provides benefits that allow real time data monitoring [1] that tells where the data is being generated, communicated to and received.

As researchers we are critical towards the perception of sound within an IoT system: is using sound in IoT for an enriched experience even possible? Interaction with technology can take place in odd, but very intimate ways [15]. By exposing potential uncomfortable and comfortable scenarios to different people we want to provoke consciousness of the invisibility of an home IoT system and show the possibility of making this perceivable. With our research we want to make them aware of a possible future reality of a home IoT environment by giving them an ‘unfamiliar - familiar’ experience. This to create an alternative perspective on what people normally could take for granted. To provoke this we have designed four different experiences to uncover if people can associate sound to the behaviour of a home IoT system, and what the emotions are that they relate to it. The experiences are based on possible future scenarios, but they have a

fictional twist. Those disrupted experiences are based on possible future scenarios.

In this paper we will try to find the possible role of sound in a home IoT system. Next to this we want to look for alternative design values within designing for IoT and sound by looking for critique points, the social role of the IoT system and we want to look at whether the system is perceived as good or bad.

THEORETICAL BACKGROUND

Weiser mentioned in Calm Technology that we moved from a world where multiple people use one computer towards a world where multiple computers use one person [5]. This is made possible because of tangible interfaces which often have been proposed as ways of leveraging ubiquitous computing effectively for humans [7]. For Weiser the rise of ubiquitous computing meant a possibility to make relevant information of systems to users more available than before and specifically in the periphery of attention. Saskia Bakker stated in Talking Tangibles that one of the preliminary results of her test is that audio could potentially be used to communicate and monitor information streams while remaining in the periphery of the attention [4]. We believe that it could be useful to implement in systems such as IoT for the reason that there are continuous information streams between the different components of such a system, while the user is never made aware of it. To design for sound in IoT is taking into account the very aspects mentioned in Talking Tangibles[4] and Calm Technology[5,7]. The experiences we created intend to make the Home IoT system information streams available to the human senses. The examples in the work of Weiser [5] and Bakker [4] show aspects that can be leveraged when designing for appropriate sound in IoT, but do not yet put it into this context.

Important elements of the prototypes in this paper are soundscapes. Franinovic & Serafin explained soundscapes as "our sonic environment, conceptualized as both our everyday environment of sounds and the musical compositions designed to improve this sonic environment" [2]. We are not sound designers and/or composers in any way, but we are interested in finding opportunities to present handles to experts in this field to contribute to further development of our proposed direction. According to us, the sonic elements of the prototypes we present in this paper fall into the before mentioned description of 'soundscapes' and through our first experiences with sound design we think we can provide starting points for further work within the field of interaction design.

Speculative design serves two purposes, it enables us to think about the future and it critiques the current practice. A design speculation consists of a bridge between the perception of the world of the audience and a fictional element. This fictional element could by anything. A 'perceptual bridge' is a means to engage the audience, we did this with 4 experiences. [6,15]. With this experiments we wanted to create a bridge in between the IoT systems that communicate with each other via the internet towards a scenario where the IoT system reveals its intentions and communicates via a soundscape. This to make people aware when the system wants to take over control or make decisions.

A research form that is used to make consumers more critical towards their everyday lives is critical design. With critical design consumers will become more aware of how their lives are mediated by assumptions, values, ideologies and behavioural norms which are normally integrated in the designs of everyday life [3, 4, 7, 16].
We want to provoke our participants to obtain a more critical look towards home IoT systems. We used our designs to bring a more critical attitude in the public. Next to this we want to look for alternative design values within designing for IoT and sound. [16]. In the paper [16] they distinguish two types of critical design: Critical Theory and Metacriticism. Where within critical theory they refer to sociocultural critiques within the philosophy and they compromise within already existing frameworks. Metacriticism on the other hand focuses on the different categories in criticism, the distinction between good and bad and the social role of the criticism[16]. Using sound as a tool to make communication perceivable within an IoT system is according to us a relatively new field of research. To research the different aspects and possibilities of sound and IoT we used a metacritical approach. The goal of the research is to find the different critique points on using sound as a system as well as the social role of the criticism and whether such home IoT systems are perceived good or bad.

RELATED WORK

This paper originated from the thoughts of how sound could be used as a communication tool for home IoT systems. An Ecological Approach to Auditory event Perception [14], gives an in depth understanding of the different types of listening that one can have and the differences between these; Musical listening and everyday listening. Where the sounds in musical listening are the sounds where the attributes of concern and the perceptual dimensions are about the sound

itself, are the sounds in everyday listening focussed on the events rather than the sounds. [14]. This paper does not yet try to map user behaviour to sounds, something that is crucial to our research, but it does give a basis on how sound can be perceived differently and how to use sound as a means of communication.

In Out To Lunch by Cohen [6] a system was designed that enlarged an ongoing 'soundscape': the typing on keyboards in an office. Cohen's prototype resembles our prototype in the sense that an ongoing process is made enlarged sonically. In our case the prototypes enlarge a process that is experienced sonically. We enlarged the background processes from different home IoT scenarios by embodying them in soundscapes. The goal of Cohen's prototype thus resembled our goal(s) in the sense that our prototypes tried to tell something about the context (home IoT system) to the user(s) by using musical listening and everyday listening in our soundscapes.

The home environment is considered to be intelligent because they 'know' their users and are 'aware' of the physical, social and cultural context, in this way they adapt in a meaningful and appropriate way. The interaction between the humans in the system and the intelligent system itself is envisioned to become intuitive and natural, they will adapt to everyday life. [17] In the 'Home radio' paper a list of general principles that are important for the design of future in an intelligent future home environment: A home should support experiences that go beyond utility and usability; people want to be creator of their own preferences; technology should move to the background and it should be trustworthy. [17] While designing the experiences we took this into account.

USER STUDY SETUP

The reason why we have set up four different experiences is to be able to shed light on the topic sound in home IoT systems from different perspectives to offer a more complete answer to our research questions.

The first experience, *Role of sound as a warning system,* focuses on determining the emotional association of sound to the home IoT environment. The *interaction with a future IoT system* wants to uncover whether the role of a home IoT system should be to guide or control the behaviour of a user. The purpose of the third experience, *The movement of sound between speaking IoT objects* is to show the movement of sound and how this calls for positive or negative reactions. Finally, *The subtlety of sound* tries to determine if there is even a possibility for people to associate sound with the system's behaviour.

All four experiences try to determine opportunities for design and future research for sound in home IoT. Together they will be able to not only answer our research question but also to complement each other with insights from different perspectives.

Role of sound as a warning system

An IoT system that communicates via sound can make decisions hearable. This makes the person in the home aware of what the system is doing at a certain moment and what it is going to do. The person in the home has the freedom to act upon this or not.

During this experience a home situation was mimicked, and a soundsketch (made with MuLab) of the IoT communication system was made hearable. The soundsketch consists of longer (2-3 seconds) tones. When the system started to communicate the tones gradually became a little higher to build tension. After it reached a certain point a randomized sound was created as a representation of the discussion between the different objects in the system.

The experiences consisted out of two different scenarios. During the experience the subject would come in the room, sit down and turn on the tv. The home IoT system decided that it was almost dinner time so it would be better if the subject would be cooking. In the first scenario the soundsketch is played to the subject. During the second scenario the same soundsketch was played but the IoT system behaved differently: it would be better if he were cooking, so the system turns off the tv and dims the lights in the living room to stimulate a change of behaviour in the subject. This to mimic different future scenarios with sound and IoT. Next to the experience an in depth casual interview about the experiences and the use of sound in home IoT where conducted, the focus in this was on the emotional association of sound and IoT.

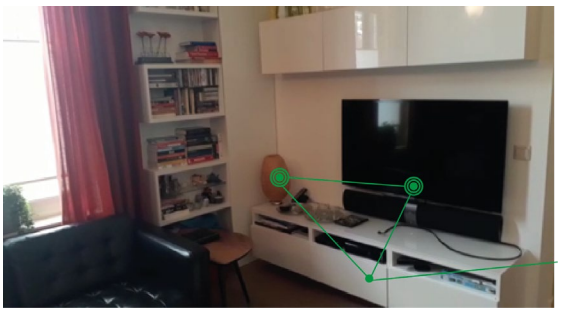

Figure 1. Visual representation of the communication of the home IoT system at a subjects home during the experience.

The interaction with a future IoT system

When different system behaviors are translated into sound manipulations, would we be able to recognise our own input? If so, are we comfortable hearing how our actions have no influence over the system and are we able to understand that the system will continue its' calculations, with and without our presence?

The software programs Processing and Abelton were used to create an interactive experience. Prior to the experience, written code was made in which we were able to manually turn virtual representations of devices from a living room on and off to give an indication of the amount of data that would be shared. The amount of devices that are told to be active in the IoT system and the amount of data that is shared within, influenced the MIDI distance between the successive notes and the tempo of a randomly produced soundscape.

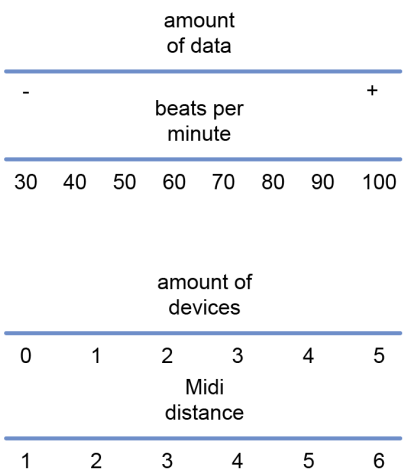

Figure 2. Data mapping.

During the experience, subjects were allowed to move and act freely throughout the actual room. In the same room, two people were present to mimic the IoT system. The first person would turn on or dim different lights from a distance and the second person would use the previously designed interface to manipulate the soundscape. Each session lasted between 10 and 40 minutes.

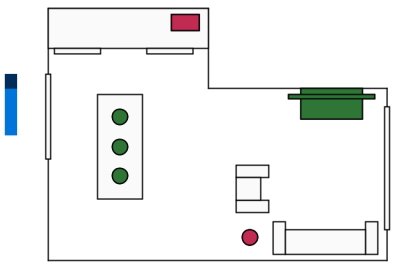

Figure 3. Screen capture of the interface to manipulate the soundscape. It shows a visual representation of the living room.

The movement of sound between speaking IoT objects.

The third prototype was a video (soundsketch), which showed two appliances of which each had a different tone to be able to differentiate between them, a tv and a water cooker, which were randomly chosen. A video of the two appliances (figure 4) was made and a soundtrack made in Logic Pro X (figure 5) was added to the video.

To experience the prototype, subjects had to listen to the video through headphones, where the two tones that were present in the video panned between left and right. The movement of the sounds indicate what type of thing was 'said' by the appliances. Each 'movement' was made more noticeable by increasing the volume of the tone that moved, bringing it more towards the center of attention of the subject.

The prototype was shown to students and staff of the department of Industrial Design. This target group is specialized in design of smart systems and services. Even though they are not specialized on sound design for IoT, they have the desired attitude towards the subject. Making them a group that might be able to bring forward aspects of our prototypes and theme (sound and IoT) that might be relevant to us and themselves in the future.

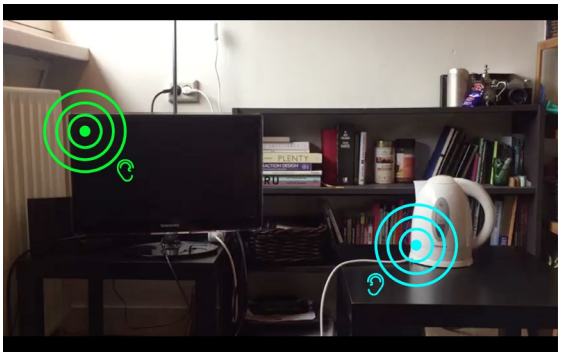

Figure 4. A still from the'movement of sound' soundsketch. The television (left) and the water cooker (right) each produce a differently pitched tone. By panning the tones and varying the volume the communication was sonified.

Figure 5. Screencapture from the Logic Pro X window of the audio file of the video. Panning and volume automation can be seen, which embodied the IoT communication in the video.

The goal of the prototype was to provoke the users into distrusting the IoT system shown in the video. The prototype attempted to do this through making the

sonified communication between the appliances confusing and hard to follow, the two sounds that embodied the appliances shifted and changed volume to confuse.
After the soundsketch was played a discussion was held about the sketch and (home) IoT in general to find points that could be relevant for the findings of this research.

The subtlety of sound.
If the IoT system communicates and we make this audible, how literal should this communication be? In this experience we opted for two contrasting types of sounds, musical and voice. To uncover which one conveys the systems communication better. This has been presented in the form of a video that showed four home scenarios; entry into the home, the IoT home on its own, the IoT home acting with no user interaction and the IoT home acting with interaction.

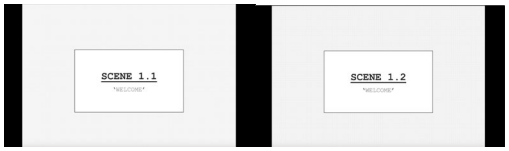

Figure 6. Screen Capture of the video experience described above. It shows the same scenario that are shown with different sounds.

Each scenario was shown twice (figure 6), of which the first time was shown with musical sounds of a string instruments produced with GarageBand (figure 7). The second time there were human voices that would talk to the user and the other elements within the IoT system.

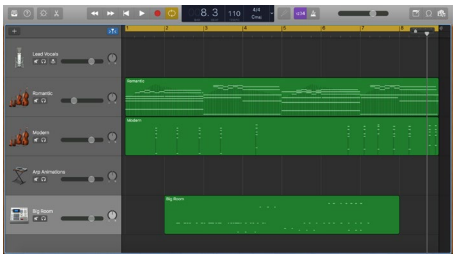

Figure 7. Screen Capture of GarageBand audio file of the different string instruments for the scene where the IoT system experienced the interaction of the user.

The video was shown to random people that live in a house. After the video was shown, a casual interview had been held with three main points of conversation: home IoT system, voice vs music and comfort. The purpose was to see how people would react to the communication between the different elements within such a IoT home system.

FINDINGS AND INTERPRETATION

From the interviews and discussions we carried out we have been able to determine some overlapping relevant themes to our research question. During these interviews and discussions we asked questions regarding their perception and interpretation of the presented experiences, as well as the role of sound within an home IoT system according to them

Can I trust my own brain?
We observed that when sound changes, subjects instinctively look into the direction of the sound source. Although not every experience used the source of sound to map IoT behavior, the first reaction of the subjects during each experience was to locate where the sound came from. Another common behavior was that subjects scared up at sudden sounds and after the experience some expressed how anxious they got or would get from sounds behind their back.

Figure 8. First reaction after the tempo of the soundscape increased: subject looks at the soundsource.

These type of observations show that the way our brains are programmed highly influence the way we perceive sonification. We might have trained our brain to process visual triggers to help us function in a modern world. Yet, as observed, our brain is still processing audible triggers as if it's in survival mode.
It requires more cognitive effort for the subjects to understand why certain sounds are changing. During '*interaction with a future IoT system*', the subjects tried to understand the reason for the sound changes through trial and error. Subjects turned devices on, off and on again, changed the distance between different devices or moved away or towards devices in an attempt to make sense of the sonification.

How do I distinguish feedback and feedforward?
An important factor in how the subjects experienced the different prototypes was whether they were able to understand the meaning of the sonification. Each prototype had its' own way to perceptualize data and

for each prototype the subjects had a different level of understanding.
Linking the sound source to the concerning devices and using voices increased the level of understanding and left less room for misinterpretation. In *Role of Sound as a Warning System* the subjects could sense that *'something'* was about to happen as the pitch of the notes increased. However this type of sonification made the users feel anxious and stressed as they didn't know what was going to happen at the perceived climax.
At times where the subjects did not understand why the sound was changing they felt uncomfortable and frustrated. They were also more likely to get startled by the effect of their own actions, since they did not expect it to happen.

> *'When I was looking at my phone I could hear that the notes followed up quicker. I wasn't sure what that meant, maybe it had something to do with the data from my phone or the system was telling me to do a certain thing.'*
> *- Interaction with Future IoT System*

Not understanding the sonification gave the subjects the feeling of being 'out of control', a sentiment that is, as we will discuss later, one of the bigger causes that makes the subjects feel uncomfortable to engage with an IoT system.

> *'How do I turn this of? It's not listening to me!'*
> *- Interaction with Future IoT System*

Can I consider myself disabled?
When asked during which practices the subject would find the sonification of a home IoT system most helpful, many of them started to imagine applications for other people.

> *'It would be nice for my grandmother, since she starts to be more forgetful.',*
> *- Role of sound as a warning system*

> *'I can imagine this can help people with a disability, for instance blind people.'*
> *- Subtlety of Sound*

Yet when we asked if the subjects would use the sonification themselves, some of the subjects stated that it would be unnecessary. The subjects were confident with their abilities and did not experience difficulties within their home environment that sonification would be able to solve.
This led to the discussion whether we all are disabled in a way, since our vision is limited to what is right in front of us. From this standpoint, subjects could see potential in how sonification would allow them to see things they currently cannot see.

> *'I would be able to hear when my daughter is using her phone again, or when someone has left the lights on upstairs.'*
> *- Interaction with Future IoT System*

Yet some subjects remained skeptical towards the idea of them being disabled and expressed annoyance during the discussion.
The subjects were more open towards sonification proposals that would support them in behavioral change, such as giving out annoying sounds when they were about to forget to recycle or giving reminders for chores.

Is sound the medicine to privacy concerns in IoT systems?
One of our primary motivations for creating experiences in which the IoT system is sonified was to provoke consciousness of the invisibility of a home IoT system. Although subjects pointed out that they did not always, or not at all, understand how to interpret the sound in the different experiences, we believe that through all experiences we've triggered a certain awareness of the presence, complexity and continuity of a home IoT system.
Because of this awareness, the subjects pointed out their concerns about their privacy and the integrity of the system.

> *'This continuous data collection, that's supposed to be there for my comfort. But I don't know where else my data is send to […] or if this thing is loyal to me or to the Albert Heijn.'*
> *- Role of sound as a warning system*

Our initial thought was that by making home IoT behavior perceivable, we would be able to weaken such concerns. We proposed a system that would give audible ques whenever data was send out of the home. The proposal had two types of responds; it was ought unnecessary by those who did not believe that an IoT system has its own morals and would therefore not misuse our personal data. The proposal would only be necessary if the system would act out of a wrong moral, in which case, the feedback would become unreliable. Such a proposal gives the system another voice through

which it could give us a sense of control and openness yet is able to deceive us at the same time.

> '*If we don't trust the president, would we give him a radio station to communicate his agenda to us? I don't think so. Why would we trust him to be honest in his communication when we didn't trust him in the first place.*'
> *- Interaction with Future IoT System*

Will I lose my identity?
Other concerns evolved around the concept that through engagement with an home IoT system, the subjects would lose parts of their identity. There is a thin line between the comfort of a home that is adjusted to the subjects' needs and the fear of a system that makes decisions for them.

> *"It reminds me of a story of a group of people that lived in a remote area, they did not want to be photographed because they were afraid that it would take parts of their identity away, I have the same feeling with such an IoT system: if the system is making decisions for me, who am I then?" - Role of sound as a warning system*

The comfort of the subjects with a system that would partly dictate their lives depended on the subjects' views. Some subjects agreed that a computer cannot be as intelligent as they are themselves, however the extent to which they felt that a computer could be intelligent differed. The spot on which comfort changes into fear was different for each person and highly depended on their view of the intelligence of an IoT system.

We asked some subjects to envision a time in which computers would have intelligence like we have and are able to make choices which would be similar or even better than our own. Most of them denied that possibility and those who did envision the scenario expressed discomfort.

> *'In a world where robots would be able to think like we do, we are replaceable. I'm starting to think that we would not be relevant at all.'*
> *- Interaction with Future IoT System*

A subject explaining why she doesn't want her home to arrange her calls:

> *'I can sense when I need to make a call to my mother, that's because I know her. I don't want my home to decide when and who I have to call, it has no idea what is appropriate'.*
> *- Interaction with Future IoT System*

A subject about that, as long as he is in control, he doesn't mind his home to make decisions for him:

> *'I want to be in control, at all times. If the lights turn on when I come home is nice and all, but if I don't want it to happen I want to be able to turn them off in an easy way.*
> *- Role of sound as a warning system*

A subject about music being a personal preference:

> *'Music is something that belongs to me. I choose it based on my mood, the time of the day and how it makes me feel.'*
> *- Interaction with Future IoT System*

Can we make such a system more human?
The different subjects expressed the sentiment of trusting humans over computers. This became noticeable from their views on privacy and computer intelligence as described above. Some subjects were convinced that by giving a home IoT system more human characteristics they would be more likely to trust and engage with it.

> *'It feels odd to have my home talk to me but if it would have familiar 'face', such as Siri or Alexa, then I would be more eager to listen to it.'*
> *- Role of Sound as a Warning System*

An antithesis was observed in *Subtlety of Sound* where some of the sound sketches included human voice. Subjects expressed discomfort when the scenario was shown in which the devices whispered to each other. Perhaps this is provoked by the associations that subjects have between whispering sounds and human behavior, where whispering is often used to sneak up to something or in moments of fear.

> *'It creeps me out.'*
> *- Subtlety of Sound*

The scenario in which the devices were talking with each other and the subject was perceived more pleasant. Although the overall vibe was friendly, some subjects expressed their concerns about their house always

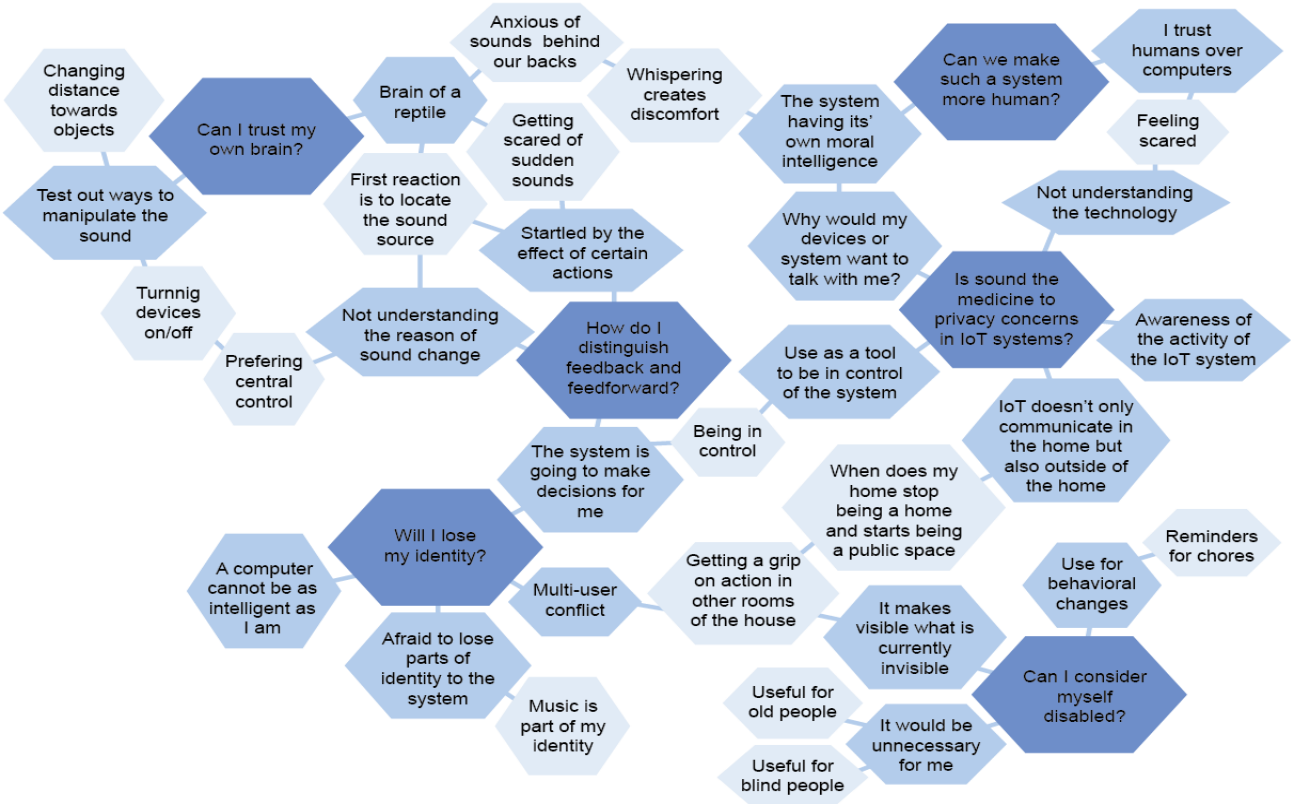

Figure 9. Overview of the thematic analysis

feeling 'busy'. The constant presence of human voices in their personal space would feel as if their house would not be personal at all. This brought another point of discussion to light: when does a home stop being a home and start being a public space?

> *'Hearing the devices talk to each other is sort of funny. But I won't feel like I'm ever alone or at home anymore.'*
> *- Subtlety of Sound*

DISCUSSION

In this paper we wanted to address the different design opportunities for sound in home IoT and what the critique points are, the social role the IoT system has and whether such a system is perceived good or bad.

The auditory examples we provided were meant as instruments to gather insights and stimulate the thought process about an under examined topic. These examples and outcomes can be used to further improve upon and to serve as examples in our proposed directions. We would like to see others further research this topic to develop more knowledge to uncover more benefits and downsides to proposed opportunities. We believe our prototypes provided handles for the combination of IoT and Sound in a different context than the works presented in the section related works.

Sound seems to make the communication streams of the home IoT perceivable, which is an positive outcome of our research. However, it does not seem to be a pleasant dictator of behaviour. This is not a fact and could potentially still be proven a misperception in future research.

In most cases the subjects of the research did see sound as a communication means in IoT as believable and as a way to make the system more perceivable. But the idea that a system could take over control and communicate their decisions via sound was perceived as bad and strange, the same for the understandability of the system's soundscape.The fear of people lies in losing control over the system and not being able to alter the system quickly. During the casual interviews those topics were addressed again and when framed differently subjects were open to a system that would help them waking up or provided support as a reminder. They thought a soundscape would be convenient as a means of communication.

Opportunities

The 6 different themes that we found can be used as an inspiration for future design and research opportunities for sound and (home) IoT. What was only meant to discover when people would be provoked by sound turned out to raise many more questions regarding

sound in IoT. We tried to determine the most relevant aspects to present for future opportunities.

A direction that different people have addressed during the casual interviews is to use sound as a communication tool within IoT for elderly, blind and other people with a (visual) handicap. One could think of a 'talking home' for visually impaired people, or a 'home that guides' elderly throughout the day. This could potentially also offer opportunities of guiding people in public spaces or to make people aware of the amount of IoT components and their behaviour present in the area that they are finding themselves in. Within this topic it would be interesting to map certain instrumental sounds to the behaviour of the different components and communication of the home IoT system.

Another research direction could be to identify in which situations people prefer to gain confirmation signals over continuous information streams. A design opportunity could be to design sound for other situations or environments where there are also continuous information streams, such as for example traffic.

Another opportunity from a design point of view is the possibility to provoke certain behaviours though negative or positive association with certain sounds. This could be used to, for example, replace the mechanical sounds of certain objects with other designed sounds that provide more information regarding its behaviour.

Limitations

Clearly there are still many unresolved questions and issues regarding the topic sound in home IoT. Even though this paper is meant to start new discussions and uncover potential design and research opportunities there are still topics, theories and limitations that we could not take into account and could potentially be of value to the subject.

Considering that sound play a big role in our research a limitation to this research topic is that we are not sound designers or composers and we do not want to showcase ourselves as if we are. We afforded ourselves to experiment with, and interpret the process of designing for sound in different ways and with different outcomes. We wanted to open up the subject of designing sound for IoT systems by being critical through our prototypes and discussions.

Another perspective on IoT systems by Frens, that we did not integrate in our prototypes, is that an IoT system's normal state is one of growth [8]. Frens' challenge was combining tangible interfaces and a systems design and how the qualities of tangible interfaces (mode of use reflected in physical state and mode relevant action possibilities) could remain helpful for users when interacting with their home environment. Our research was meant to provide insights on how sound could provide handles in designing for home IoT, but the growing systems phenomenon was not elucidated in our prototypes. The reason to combine tangible and embodied interaction with IoT systems according to Frens was that visual user interfaces require focus and cognitive effort, which can overload the user with information. Our work did not directly take into account the growth phenomenon in IoT, but future work on sound in IoT might find it valuable to integrate it because of the opportunities sound has with peripheral interaction.

From the discussions we noticed that IoT on it self is already a very controversial topic. This made the interviews and discussions very interesting, but a downside to this is that at times it was hard to differentiate the opinion regarding IoT from the opinions about sound in IoT.

CONCLUSION

One could say that this is merely a beginning to much more design and research with sound in IoT. In this paper we have discussed sound in IoT within the home environment, but this can certainly be applied to other IoT environments.

We hope to have made clear that there certainly are opportunities for sound within home IoT by giving new insights to this topic. In the discussion have addressed a potential target group, which are mainly visually impaired and elderly. Next to that there are the opportunities regarding the mapping of sounds to behaviour which is a big topic with many opportunities.

Sound for home IoT is a relatively new topic that still has to find its specific purpose in design and research.

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REFERENCES

1. Hermann, T., & Hunt, A. (2011). *The sonification handbook* (pp. 399-425). J. G. Neuhoff (Ed.). Berlin, Germany: Logos Verlag.
2. Franinović, K., & Serafin, S. (Eds.). (2013). *Sonic interaction design*. Mit Press.
3. Dunne, A. (2006). Hertzian Tales: Electronic Products,Aesthetic Experience, and Critical Design. MIT Press.
4. Dunne, A., and Raby, F. (2001). Design Noir:The Secret Life of Electronic Objects. Birkhäuser.
5. Weiser, M., & Brown, J. S. (1997). The coming age of calm technology. In *Beyond calculation* (pp. 75-85). Springer, New York, NY.
6. Cohen, J. (1994). Out to lunch: Further adventures monitoring background activity. Georgia Institute of Technology.
7. Ishii, H., & Ullmer, B. (1997, March). Tangible bits: towards seamless interfaces between people, bits and atoms. In *Proceedings of the ACM SIGCHI Conference on Human factors in computing systems* (pp. 234-241). ACM.
8. Frens, J. (2017). Designing for embodied and rich interaction in home IoT. In *Proceedings of the Conference on Design and Semantics of Form and Movement-Sense and Sensitivity, DeSForM 2017*. InTech.
9. Google Home. (n.d.). Retrieved from https://store.google.com/product/google_home
10. Echo (2nd Generation) - Smart speaker with Alexa - Charcoal Fabric. (n.d.). Retrieved from https://www.amazon.com/all-new-amazon-echo-speaker-with-wifi-alexa-dark-charcoal/dp/B06XCM9LJ4
11. Toon, de slimme thermostaat. (n.d.). Retrieved from https://www.eneco.nl/energieproducten/toon-thermostaat/
12. I. (n.d.). IFTTT helps your apps and devices work together. Retrieved from https://ifttt.com/
13. De Mauro, A., Greco, M., & Grimaldi, M. (2015, February). What is big data? A consensual definition and a review of key research topics. In *AIP conference proceedings* (Vol. 1644, No. 1, pp. 97-104). AIP.
14. Gaver, W. W. (1993). What in the world do we hear?: An ecological approach to auditory event perception. *Ecological psychology*, *5*(1), 1-29.
15. Auger, J. (2013). Speculative design: crafting the speculation. *Digital Creativity*, *24*(1), 11-35.
16. Bardzell, J., & Bardzell, S. (2013, April). What is critical about critical design?. In *Proceedings of the SIGCHI conference on human factors in computing systems* (pp. 3297-3306). ACM.
17. Eggen, B., Rozendaal, M., & Schimmel, O. (2003). Home Radio: Extending the home experience beyond the physical boundaries of the house. In *HOIT*.

APPENDIX BACKGROUND AND CONTRIBUTION

Lesley Lock:

MSc. student Industrial Design at the Eindhoven University of Technology. Interested in aesthetics of interaction and how aesthetics of interaction can create new relationships between products and users that are more focussed on experience than functionality. His contribution was mainly in the stating of the provocation in the beginning of the process (can we trust IoT) and setting directions to work from; the design of the '*The movement of sound between speaking IoT objects.'* prototype and deploying it; contacting researchers at the ID department to be able to grasp what design research is about, what the context is for the use of sound in IoT, and what the showroom methodology is about. Like all authors of this paper he was involved in the writing of the paper.

Marit Proper:

Msc. student Industrial Design at the Eindhoven University of Technology. Interested in design for future personalised healthcare with a focus on user interaction, intuitive design and multi stakeholder involvement. This to bridge the gap between designer, user and client.

Her contribution was to design the experience: *Role of sound as a warning system* and carrying out the casual interviews regarding the experience. Next to this she analysed this data and helped with constructing the main themes of the paper. She has written part of the theoretical background, related work, discussion and introduction. Also did she revise and rewrite parts of the paper to try to make a coherent research text to answer our research questions.

Nine Sellier:

MSc. Student Industrial Design at the Eindhoven University of Technology. Interested in user psychology, user interaction and how design can be used for behavioral change. Her contribution was

mainly in defining the different experiences; the design of *'Interaction with a future IoT system'*; prototype and deploying it and the thematic analyses and description of the collective findings. Like all authors of this paper she was involved in the writing of this paper.

Julia van Zilt:
MSc. student Industrial Design at the Eindhoven University of Technology.
Interested to bridge the current gap between technology and the human body, specifically within the area of wearables. For this to provoke intuitive interaction through aesthetics.
Her contribution was to design the experience, *subtlety of sound*, and to carry out the interviews and discussions of this experience. After this, she gathered the findings from this and determined together with the rest the most relevant quotes and themes. She tried to bring the different perspectives on the topic together to create a coherent story line. Furthermore has she been in charge of gathering the ideas for the abstract, keywords, introduction, future opportunities, conclusion and acknowledgements and making this into a coherent text. She has written part of the theoretical background, related work, user set up. Together with others she approached relevant researchers of the department of Industrial Design to get feedback on the design and research process and content. Also did she revise and rewrite the paper at the end of the process to try to make a coherent research text to answer our research question.