Experimenting techniques for sonic implicit interactions: a real time sonification of body-textile heat exchange with sound augmented fabrics

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ABSTRACT

In this paper we present our prototype of a sound augmented blanket. With this artifact we aim to investigate the potential to achieve sonic implicit interactions through auditory augmentation of fabrics. We describe the development of a blanket that sonifies the approximate temperature exchange between the body and the fabric, using sound as a medium of interaction and a carrier of information. We propose different methods for auditory augmentation of fabrics through a piezoelectric contact microphone used for movement sensing. After describing the technical development of the prototype, we discuss our early findings from a qualitative standpoint, focusing on the process of sense-making of such an artifact from an evaluation based on free exploration. Our preliminary results suggest that different auditory augmentation models encourage different affordances, and are able to provide a simple creative and aesthetic experience. The ability of the chosen sonic interaction models to effectively communicate information should however be further investigated.

1. INTRODUCTION

Smart home automation systems, based on Internet of Things (IoT) technology, are growing in popularity in recent years also due to the benefits, in terms of energy efficiency, they can facilitate. However, research [1, 2] shows that the process of deployment of distributed computing in the household can, depending on how it is implemented and presented to users, have undesirable consequences, such as legitimization of unsustainable energy practices [2] and reinforcement of gender-related power dynamics [3]. The reasons for these shortcomings might be related to the ways these interfaces are designed, but also to the ideological positions they reflect. As argued by Gaver (2002) [4], digital technologies are associated to ideologies and values from workplaces - the contexts for which they were originally designed - and are usually devised to achieve a clear unique and specific function. This should be kept in mind when designing interfaces for the home, an environment in which priorities and intended functions of objects can be radically different. Several examples from HCI propose alternative designs that critically engage in this discussion. Some authors, for example, advocate for technologies that operate at the periphery of attention [5], encourage creativity [6], playfulness and wonder [4], designing for 'downtime' [7], 'slow time' [8] and prioritize simplicity [9].

Following these premises, we experimented with sound as an interaction medium and as a carrier of information in the household through auditory augmentation of textile materials, exploring the potential of sounds to deploy a creative, un-intrusive aesthetic experience. We developed the prototype of a sound-augmented blanket that sonifies the approximate energy exchange between the body and the fabric in terms of heat, reflecting on the discourses on energy efficiency and household digitalisation by raising awareness of the hidden or un-measurable energy savings in terms of heating that can be obtained with simple actions such as covering the body with a blanket. Specifically, in this paper we explore the potential of sonic implicit interactions, interactions that are not initiated by the user explicitly [10, 11], to communicate information at the periphery of attention while embedded in fabrics. In this contribution we describe the technical realization of our artifact, the employed sonic interaction strategies, and explore the initial approach and sense-making process of users to the auditory augmentation of a regular household object, in this case a blanket [1] .

2. BACKGROUND AND RELATED WORK

2.1 HCI for energy in the household

Households are receiving increasing attention in research about energy efficiency, however developing effective ways to encourage less energy-intensive behaviour is not a trivial task. Different approaches have been attempted in the field of HCI, usually exploiting recent Smart Home technologies which can provide a large amount of sensor data about different aspects of energy consumption. These data are usually presented to users in the form of numeric, often visual, eco-feedback and used to drive home automation technologies in which users take on the role of managers. Despite substantial research, the degree of these systems' effectiveness in the long term is not clear [12]. Some authors argue that the assumptions behind this approach are too simplistic to suit the operations of a complex socio-

[1] All of the code used for this paper, including the interaction mappings and the sound models, can be found in open-source at https://github.com/vincenzomadaghiele/Sound-augmented-fabrics.

technical system such as a household [1,6]. Strengers (2014) [13] argues that the reasons for the shortcomings might be found in the premises behind their design, which are deemed unrealistic and seem to overlook what people actually do in their home.

Some examples of such energy awareness artifacts include the Power-Aware Cord [14], the Energy-Aware Clock [15], lamps that change their color based on energy consumption [16], and audiovisual installations [17]. The *Static!* research group [18] built prototypes to promote critical reflection on energy usage. Design objects can also be related to unconventional ways of harvesting energy, such as micro-scavenging devices to capture energy from mechanical, thermal or light sources [19] or hand-powered electrical devices. In some research the focus has been shifted from individual users to communities, for example exploring interfaces for communication of demand response, load shifting [20] and energy forecasts in distributed settings [21]. Another way of introducing interactions in the home environment is to exploit the affordances present in the room itself. This feedback method has been proposed by Menon et al. (2021) [22] and promotes the idea of a shift in design focus from a user-centered perspective to a space-based approach, proposing the use of animistic principles to induce in users empathy for the space. Some relevant sound-based interventions for energy efficiency include the sonification of water consumption in the shower [23], water consumption regulation through singing [24], the sonification of energy data through interaction with a carpet [25], the real-time sonification of the electric power consumption of an institute's kitchen through auditory augmentation of the space [26], the *Powerchord* project (2016) [27] and *Bird-Wattching*, power consumption sonification in the kitchen using bird sounds [28]. Additionally, novel methods to explore connections between the household soundscape and concepts of energy efficiency [29] are being investigated.

2.2 Sonic implicit interactions

As our life is more and more surrounded by digital technology, research is starting to explore how we can make human-computer interactions less demanding, for example reducing the amount of attention interfaces require. Most of the currently employed digital interfaces involve some kind of explicit user input - pressing a button, entering a command and so on. These modes of communication are defined as **explicit interactions** [30]. These kinds of interfaces do not take into account the complexity of non-verbal communication that humans use to acquire knowledge about situations as well as to interact among each other and with the world. A way to obtain more seamless and user-friendly interfaces is by developing **implicit interactions**, which are defined as "an action performed by the user that is not primarily aimed to interact with a computerised system but which such a system understands as input" [10]. Often in implicit interactions the exchange of information occurs outside the attentional foreground of the user. When assessing implicit interactions, it is important to evaluate the amount of attentional demand they require, defined as "the degree of cognitive or perceptual focalization, concentration, and consciousness required of the user" [30]. A deeper evaluation of attentional demand involves looking at aspects such as spatiality, breadth and intensity. Sound is a particularly suited means for implicit interactions, as often it does not require the complete focus of the user's attention. In our everyday lives, sounds can be implicitly felt and understood, still providing feedback with minimal attentional demand.

Not much research has been dedicated to the pursuit of sonic implicit interactions [11], however the relationship between movements and sounds, often aspects of implicit interactions, has been object of substantial research. For example, the sonic affordances of gestures have been studied by Altavilla et al. (2013) [31], who described participants opinion of sound-gesture mappings. The sonic augmentation of everyday objects has been experimented by Franinovic et al. (2011) [32]. Sound-gesture mappings have been the object of research in the Sonic Interaction Design [33] and New Interfaces for Musical Expression (NIME) communities [34].

2.3 Sonic textile interfaces

The relationship between fabrics and sound is historically significant: the sound-absorption properties of textile materials [35–37] have been exploited for sound insulation for centuries. Moreover, the sounds themselves of fabrics of different materials have been shown to be linked to auditory comfort and emotional responses at a physiological level [38]. Pauletto (2022) [11] points out that the experience of Foley in cinema can be of great inspiration when dealing with sonic interactions, as bodily interactions with different textiles are certainly a large part of the Foley sonic palette. Elblaus et al. (2015) [39] developed an interactive sound-augmented garment to investigate the functional aestehtics that emerged with the introduction of sonic affordances, noting how the presence of sound changed the design priorities and the usage of the garment. Additionally, the works of Nabil et al. (2021) [40] and Prindl et al. (2020) [41], who are developing fabric speakers for application on clothes, are of great interest for this project.

3. MOTIVATIONS AND CONTEXT

In this project, we are developing sound-augmented fabrics which sonify real-time heat exchange between themselves and the body, with the aim to make users aware of energy exchanges and savings that are not usually measured and quantified in their daily life. More generally, these artifacts are tools to question the role of computing technologies in the household, proposing an alternative way to display data in this environment which is flexible, playful and leaves a degree of ambiguity. Specifically, in this paper we focus on the potential of sound to communicate information in the household through subtle, sporadic interactions, how can these interactions be embedded in textile materials through piezoelectric elements, and users' early approach to auditory augmentations of such materials.

We developed two alternative sonic augmentation models by using the normal sound of the blanket as input, sensed with a piezolectric contact microphone, such that the sounds would coordinate with the movements of the fabric. In our initial evaluation we started to explore the trade-off between clarity of information display and aesthetic acceptability of the sound model, with the aim of it to be integrated in daily practices and routines. The blanket proved to be an appropriate tool for this investigation, since it is extremely simple and flexible, it can cover a great range of functions and case uses.

4. SYSTEM DESIGN

We decided to utilise the natural sound of the body against the moving fabric as primary sonic material for our sound models. The data being sonified in real-time is the heat being exchanged between the body and the blanket. This objective presented a number of challenges on the technical side. For example, the flexibility and constant movements of the fabric requires to build a solid and testable prototype with relatively small components, in such a way that the electronics do not condition the usage too much. The most challenging aspect in the design phase - and a main subject of our evaluation - regards the complexity of the sound models to be developed: sound models that are too complex might be difficult to interpret; on the other hand sound models perceived to be too simple might be not engaging enough.

4.1 Physical prototyping

The base element of our prototype was a normal house blanket of polyester material of dimensions 114 cm by 152 cm. The electronic components were sewed to the fabric such that they were securely attached and resisted to the movement. As can be seen in Figure 1, all of the components were on the same side of the blanket, which was intended to be the side in contact with the body. We used a Bela Mini embedded platform [42] to process the input from a LM35 temperature sensor and a piezoelectric disk with the Pure Data programming language [43]. Since our aim was to augment the natural sound of the object, we decided to place the speaker directly onto the blanket. The sonic output from the Bela platform was therefore routed to a small 4 Ohm speaker, amplified through a Mono 2.5W Class D Audio Amplifier [44]. The Bela was powered by a small LiPo battery.

After some experimentation, we decided to place the Bela - the heaviest component - on one corner of the blanket, so that the body movements do not destabilize the electronic connections. The piezo disk was placed in the center of the blanket, slightly shifted to one side. The temperature sensor was also placed close to the center of the blanket, with the assumption that it would be the closest point to the body. Choosing the position of the sensor was challenging, since it is difficult to foresee how different users would wear the blanket. We placed the speaker facing the side of the electronics, closer to the longer edge of the blanket.

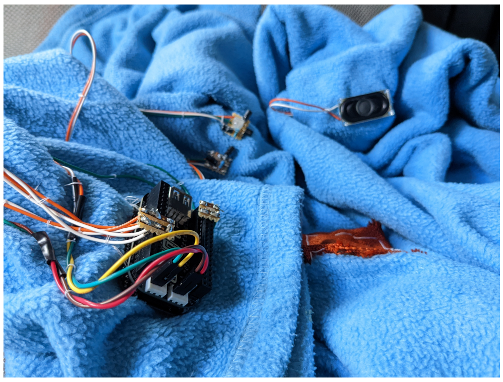

Figure 1. Sound-augmented blanket prototype. The piezo disk is inside the orange patch, which was tightly stitched to the blanket to maintain close contact.

4.2 Body heat and energy exchange

Heat exchange between the human body and the environment is a complex phenomenon which is a combination of multiple physical processes. Heat is generated in the human body by metabolic processes and it is exchanged with the environment through conduction, convection, evaporation and radiation. The amount of heat exchanged between the body and the environment can be approximated with Equation 1 [45, 46].

$$Q_i = h_i A_D(\overline{T_s} - T_o) \tag{1}$$

In Equation 1, Q_i is the amount of heat exchanged between the body and the environment at conditions of $\overline{T_s}$ average body surface temperature and T_o environmental temperature - in our case the supposed temperature of the blanket. In our software implementation, the average environmental temperature was approximated to $T_o = 30$ °C, while $\overline{T_s}$ is the temperature retrieved by the LM35 sensor, which we associate to the body temperature. h_i is the heat exchange coefficient, which is in the case of this model approximated to just the free convection value, which amount to $2.3W/m^2K$. A_D is in this case *Du Bois' body surface* approximation [47], as in Equation 2, in which m is the body mass in kilograms [kg] and h is the body height in meters [m].

$$A_D = 0.202m^{0.425}h^{0.725} \tag{2}$$

The values of m and h were approximated to the average weight and height in the Swedish population, respectively $1.74m$ and $74.3kg$ [2].

4.3 Sonic interactions and sonification design

We used the sound signal from a piezoelectric contact microphone to detect movements in the fabric, activating different sound models accordingly. The direct sound coming from the piezo disk was pre-processed as in Figure 2: to adjust the sensitivity of the piezo disk, the incoming sound was multiplied by a constant (the amount of sensitivity) and then processed through a hyperbolic tangent function,

[2] Information from Dagens Nyether - Svenskarna längre och tyngre.

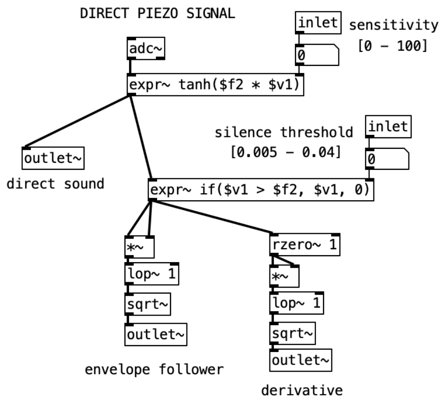

Figure 2. Digital pre-processing of the audio signal from the piezo disk.

which allowed to amplify the lower-volume components - corresponding to interactions that were further from the disk - without increasing the amplitude of the higher volume sounds. An adjustable threshold was applied to the signal to filter out background noise when the fabric is not moving. The envelope of the sound and its derivative were also calculated.

Our sonification models were inspired by recent research on shared semantic connotation of sound attributes [48, 49]. Specifically, we focused on the definition of *warm* sounds, as described by Rosi et al. (2020) [48]:

> A warm sound seems to be a low-pitched or mid-low-pitched sound. It gives a feeling of spectral richness in the mid-low frequencies. It has a rather soft attack and it is a fairly pleasant sound for the listener, giving a sensation of envelopment.

In our sonifications, a higher amount of heat exchange was expressed by a *warmer* sound. We experimented with the following techniques, which may be employed together or separately. The strategies to achieve the *warm* sonification metaphor are different for the two models, as is the way in which sound responds to interactions with the fabric.

1. **Real-time granular synthesis (Model 1):** the piezo audio signal is used as the input of a real-time granular synthesizer [3] whose parameters are mapped to the heat data. The *warm* sonification is in this case obtained by mapping increases in heat exchange to higher octave transposition of the sound and a shorter live-recording window. Higher heat was also mapped to lower frequency cutoff of a low pass filter at the end of the chain, to obtain a smoother sound with less high frequency components.

2. **Envelope-follower (Model 2):** the audio signal from the piezo element is used to drive an envelope follower which controls the activation of a synthesizer. To obtain an organic interaction, the derivative of the signal controls small pitch variations. The heat data influences the parameters of the synthesizer employed - in our case a bank of sawtooth oscillators with different amounts of detuning. The *warm* metaphor is obtained by increasing the amplitude of the oscillators that are detuned down as the heat increases, and decreasing the amplitude of higher harmonics to obtain a richer spectrum with more low-end components.

[3] The real-time granular synthesizer employed is based on an implementation by Johannes Kreidler, released at `http://pd-tutorial.com/english/ch03s07.html`.

Since the envelope has been found to be an important perceptual component in this semantic sound characterization [49], in all of the aforementioned cases the data influences not only the spectral qualities of the sound, but also the reactivity of the sound envelope, with *warmer* sounds corresponding to a slower attack and decay. Finally, the direct audio signal coming from the piezo was also included in the mix, to emphasize the connection between the synthesized sound and the sound produced by the blanket movements.

5. EVALUATION METHOD

We performed an initial qualitative evaluation procedure with the aim of gathering an initial understanding how people relate to our prototype. The participants were six PhD researchers in our Division, three women and three men. The test lasted approximately 25 minutes, and was run in a quiet sonic environment, the MID Media Production studio at KTH Royal Institute of Technology.

Participants were told that the sounds on the blanket would respond to their movements and the temperature between the fabric and the body, and they were given freedom to explore the object and move freely. At this stage, we were interested in evaluating the experience and interaction as a whole, so we purposely did not put great emphasis on explaining that the sound would provide information about the warmth provided by the blanket. We did not want the participants to focus specifically on whether they "heard" the increase in warmth, instead we wanted to observe what the object suggested to them and how they experienced the interaction with it. The two sound models were evaluated separately, starting from Model 1 and then changing to Model 2. Participants were asked to freely describe their experience while moving, and then to answer the following questions:

1. *How would you describe your experience with the blanket?*
2. *Which was your favorite aspect about it?*
3. *Is there something you would change? If yes, what and why?*
4. *Which one was your preferred sound model and why?*
5. *Could you imagine using an object like this in your daily life?*

We focused our evaluation on the interaction component, aiming to understand if and how the augmented sound component influenced the normal interactions with the blanket, and which interactions are encouraged by the two different sound models, which yielded two significantly different aesthetic experiences. Model 1 is more reactive, organic and complex. Model 2 has a slightly lower volume, it is milder and it has a lower internal complexity.

6. DISCUSSION

6.1 Initial approaches to sonic augmentation

As participants were given no instruction on how to interact with the blanket, diverse initial approaches to the exploration of the object emerged. A preliminary remark is that the exposed electronics limited the interactions, as most participants feared breaking parts of it.

After an initial stage of careful exploration of the sound-movement relationship, two different ways of approaching more complex interactions could be identified: some participants interacted with the object as they would with a normal blanket, trying to imagine how the sound component would influence the activity they normally do with a blanket; some other participants were not interested in finding real-life use cases and they focused on the sonic output, approaching the blanket as a sound-making object and talking about it as a musical instrument. This difference was reflected in the movements they produced. In the first case, the sound was a consequence of the movements, while, in the second, the movements were adjusted to explore the sonic response. These two ways of approaching the object generated different aesthetic experiences and specific use cases emerged.

6.2 Affordances of sonic interaction models

The potential for implicit interaction can be observed from the afforded movements generated by the sonic artifact. The two sound models in this experiment promoted different interaction strategies and produced different sonic content. Based on the interactions afforded by the two models, one could notice that the milder sonic quality of Model 2 stimulated more repetitive, less demanding interactions, while the higher perceived complexity of Model 1 prompted more ample gestures and focused exploration.

The affordances of the object could be recognized from the ways in which participants interacted with it. Some people were mainly seated, delicately exploring the surface of the fabric to investigate the sonic output with the blanket on their lap, while others preferred walking around the room and moving their body in contact with the blanket. A common way of engaging with it was to wear it as a cape and walk, even though this action was not described as a way they would use a blanket in real life. Another way to explore the interactions was to stand in one spot and move the body. For example, Participant 2 tried different yoga poses to with the blanket on, and Participant 5 tried wearing the blanket on their body in different ways, including putting it over their head.

Interactions with ample, complex movements were prompted by Model 1, as it was considered more organic and reactive, while Model 2 was perceived as being quieter and more stable by participants, encouraging fewer movements and subtle, repetitive actions. For example, most participants, when experiencing sound model 2, ended up with the blanket on their lap, slowly and repetitively stroking it in proximity of the piezo disc while answering the questions at the end of the test. Participant 1 decided to lay down on the floor with the blanket on their belly, slowly breathing as the warming body and the breathing movements generated a slow and repetitive sound. Meditation was a common theme that spontaneously emerged in multiple interactions, with different participants proposing different ways of meditating with it, through movement (Participant 2), breathing (Participant 1) or as a fidgeting device (Participant 5). Another proposed use cases including using it as a low-attention aesthetic experience alternative to watching television when tired.

6.3 Ambiguity and function

The connection between sound and temperature was not perceived clearly by any of the participants, some of which were however able to implicitly understand the connection between the position of the temperature sensor and the change in sound and using it consciously to produce changes in sounds in relation to movements, such as rubbing the blanket surface on the sensor. This is probably due to the position of the sensor, which made its measurement vulnerable to movements, and to the complexity of the sound models, which made it difficult to separate the effect of the temperature from the effect of movements on the sounds - especially since this aspect was not very clearly explained to participants before the test.

Despite these technical limitations, ambiguity was indeed, at this stage of prototyping, inherent to the design. Differently from most digital technologies, the sound-augmented blanket is purposely not focused on optimizing a specific action, but rather it is communicating, expressing an information - in this case temperature - about itself and the surface it is in contact with, which is usually a human body. Some participants found this ambiguity frustrating and were asking about its function, intended use cases and the information it was trying to communicate. For example, Participant 6 stated:

> A little disorienting. The association of a blanket with the sound is what I find not intuitive. I struggle a bit to see what, or how am I to interact with this or for what purpose. [...] It's important to have some sort of information about what I am supposed to do and be able to clearly understand how it reacts and how it responds.

Nevertheless, ambiguity brought up some interesting aspects, with some participants attributing a degree of agency to the artifact, saying that "it's angry" or "like a cat" (Participant 4), or saying: "I find it interesting to communicate with a blanket. I think there's something intellectually stimulating about that idea." (Participant 6). These minimal attributions of agency could be related to the ambiguity of the artifact in terms of function, combined with the reactivity of its sonic response; this aspect however needs further investigation. Not all users found the ambiguity problematic; some approached the artifact as a musical instrument or a meditation device and were just curious about imagining or inventing what functions it could have.

7. CONCLUSIONS

In this paper we presented our initial prototype of a sound-augmented blanket. We argued for different priorities in design with data for the home, proposing an alternative approach to data sonification for the household environment. Our overarching aim is to expose hidden energy that is usually not accounted for by sensor-based digital energy measurements. We have experimented with different ways to implement this design approach to create sonic implicit interactions. Our sound design was informed by recent studies about shared semantic connotation of sounds. We have then run a simple evaluation with multiple users comparing different interaction strategies, to observe the inital approach to our artifact and the sense-making process related to the sonic augmentation of a common household object.

Overall, we observed that implementing sonic augmentation can radically change the perceived affordances of a common object. The sonic characteristics of the augmentation are crucial in shaping the afforded movements, as the two alternative sound models encouraged very different interactions, leading users to imagine different use cases for this object in their everyday life. The mapping of sound to movements in the two models was satisfactory in different ways for participants, and it was successfully able to adapt to different interactions. The association between a change in sound and a change in temperature did not clearly emerge from the experience, and we speculate that this could be due to peculiarities of the current sound models and the way in which participants interacted with the object. The sound-augmented blanket proved to be a very flexible object that was able to spark curiosity on a first approach and was indeed used creatively by participants to develop a range of simple and very personal aesthetic experiences, which were different depending on the users' imagination, personality and use cases.

Future work will include the development of multiple alternative prototypes, in which different materials will be tested, and the relationship between material, movement, sound and warmth will be further investigated, as well as a longitudinal study in which we would investigate if the acceptability of our sonic interactions is sustained over a long period of time.

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