INFODROPS: SONIFICATION FOR ENHANCED AWARENESS OF RESOURCE CONSUMPTION IN THE SHOWER

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ABSTRACT

Although most of us strive to develop a sustainable and less resource-intensive behavior, this unfortunately is a difficult task, because often we are unaware of relevant information, or our focus of attention lies elsewhere. Based on this observation, we present a new approach for an unobtrusive and affective ambient auditory information display to become and stay aware of water and energy consumption while taking a shower.

Using the interaction sound of waterdrops falling onto the bathtub as a carrier for information, our system supports users to be in touch with resource-related variables. We explore the usage of an affective dimension as an additional layer of information and introduce our 4/5-factor approach to adapt the auditory display's output so that it supports a slow but steady adjustment of the personal showering habit over time.

We present and discuss several alternative sound and interaction designs.

1. INTRODUCTION

Although seemingly abundant for many of us, water is a precious resource and more than a quarter of the world's population live in regions that will experience severe water scarcity within the first quarter of this century [1]. At the same time, taking a shower in the western world usually uses up more water than the typical person living in a developing country uses in a whole day [2], which makes a reduction of water consumption both desirable and feasible.

One might argue that in some regions, as for example in Germany, reducing local water usage is unnecessary due to frequent rainfall, or even detrimental to the environment as the (oversized) canal system has to be flushed with *additional* freshwater in order to prevent clogged sewer lines [3]. However, we have to keep in mind that showering not only uses lots of water, but also a significant amount of energy to heat it: In the United States, for example, domestic water heating accounts for between 15 and 25 percent of the energy consumed in homes [4].

A fundamental cause of our high resource consumption is that people are normally not particularly aware of, for example, how much energy they consume, and how this affects either their financial budget, the environment or the ecological systems. This, in turn, is caused by the fact that their focus of attention is, of course, mostly on their main task, in this case on cleaning the body, relaxing, etc.

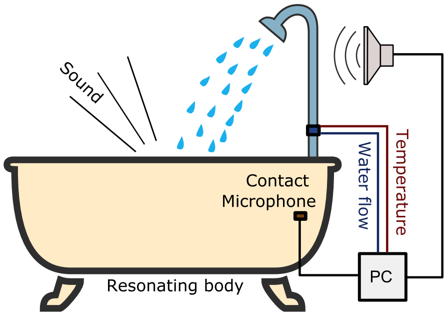


Figure 1: Hardware setup of our auditory display: Based on the current water flow and temperature data, the sound that is picked up by the contact microphone is processed and, through a speaker, directly fed back to the user.

The above problem has been identified in related work as reported in Sec. 2 and several approaches have been considered, largely relying on visual displays and rarely using non-speech auditory display. We argue that sound has many advantages compared to visual display, such as allowing eyes-free awareness, backgrounding / high sensitivity to changes, guidance of attention, which have not been exploited yet for resource-awareness applications. Particularly, we regard the *affective* dimension of sound as an important still neglected carrier of information when it comes to displays that shall be effective on the (sub-)liminal level of conscious processing. Similar to prosodic cues such as for instance emotional tone in verbal speech, affective information levels can overlay an additional information layer over the functional level of an auditory display to refine and adapt its output to influence users. If done rightly, and the display being understood by users these may prove superior to pure functional displays in helping users reaching their goals.

In this paper we present a new approach for such an unobtrusive, affective ambient auditory information display to help users attaining certain behavioral goals, more specifically here demonstrated with the case of reducing resource consumption while tak-

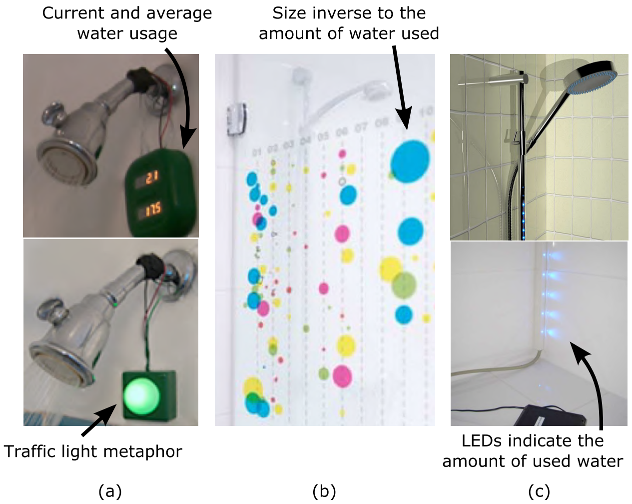


Figure 2: Pictures of related work concerned with reducing water usage in the shower. (a) shows a numeric visual display as well as an ambient display incorporating a traphic-light metaphor from *UpStream* [7]. (b) illustrates the *shower calendar* [8]: Each dot represents the leftovers of using 60 liters of water. A design concept and prototype of *Show-me* [9] is shown in (c): For every five liters consumed, an additional LED is switched on.

ing a shower. However, we are confident that the methods and techniques developed on the way can be applied to many other application cases as well, as later suggested in the discussion.

Concerning the sonification method, we introduce a sound-coupled *blended sonification* method (as introduced in a companion paper by Tünnermann et al. in this volume [5]), where environmental sounds – in our case the water falling into the bathtub – are picked up and processed in real-time to render transient-triggered functional sounds that merge with the existing sounds into a perceptual unit. This approach inherits yet modifies ideas previously introduced as auditory augmentation in [6]. We present several specific mappings for the auditory display and discuss their pros and cons as to affect users. As a novel conceptual element we introduce the *4/5-factor* approach to continuously and smoothly adapt personalized feedback over time to induce a gradual and sustained change of behavior. We demonstrate the resulting design in an implemented running system installed in a shower. An empirical evaluation in longitudinal studies is planned after the system and sound design converge. For this we hope for an inspiring discussion at ICAD.

The paper begins with reporting related work on resource awareness systems in the shower, followed by an analysis of typical showering patterns in Section 3. We then discuss several approaches for the design of the system, after which we introduce the *4/5-factor* principle in Section 5. Based on the final design of our ‘transient-triggered affective blended sonification’, we provide details on the technical implementation in Section 6, followed by a brief description of selected sound examples. We conclude with a discussion of the results and prospects for future work.

2. RELATED WORK

Kappel and Grechenig were, to our knowledge, the first to develop an ambient display dealing with resource consumption in the shower. Their display shows the amount of water used during a shower with an array of LEDs that are vertically assembled on a stick [9]. Their setup, however, only allows for a very coarse display of water consumption (five liters for each LED) and does not account for the energy used to heat the water.

While it is an ambient display in the sense that the presented information is easy to comprehend, the user still has to look at it, which can be quite difficult when actually having a shower. Furthermore, it does not support the explicit setting of a goal nor does it help the user to attain it – e.g. by highlighting the discrepancies between a goal and the actual consumption.

Laschke et al. introduced a shower calendar that displays the water usager per shower during a whole year [8]: For each shower taken, it displays a dot, whose size corresponds to the leftovers of using 60 liters, i.e. the larger the dot, the less water was used during the shower. Additionally, for use in a family-context, the dots are of different colors in order to distinguish between the consumptions of the family members. By design, this installation gives feedback only *after* each shower und thus can not give any guidance during it.

While the visualization is well chosen in that it rewards a reduced consumption with larger dots, one could also argue that it is ambiguous in that there is little difference between *not* taking a shower (no dots) and using lots of water (only small dots visible). In result, it does not only “beautify” a reduced water consumption per shower, but also a more frequent usage.

Arroyo et al. prototyped several interventions aimed at influencing the behavior and use of water in the domain of the sink. This includes HeatSink, which illuminates the water from a faucet based on its temperature, and Waterbot, which, similar to “show-me”, displays the current and average household water consumption by means of two illuminated bar graphs [10]. Additionally, this installation gives auditory feedback, although only by playing chime sounds or prerecorded voice feedback when the tap has been closed.

Kuznetsov and Paulos compared their ambient feedback device to a numerical display of the water consumption during a shower, concluding that “the numeric display was ultimately less liked and less effective, despite participants’ initial preference for the numerical modality” [7].

Both the numeric and ambient display showed the current water usage compared to a reference consumption, which had been measured before, without any other feedback, and the reference didn’t change over time. Their feedback device uses a traffic light metaphor and thus can essentially only display three different states (below average, above average and 150% above average), which is not only a very coarse measurement, but obviously also can not give any guidance for a controlled *reduction* of water usage. One of the study participants noted that the display was “very hard to see” while showering.

3. UNDERSTANDING SHOWERING PATTERNS

Although seemingly a mundane and simple routine, it is worth to first have a more detailed look at the process of showering itself. From a perspective of energy usage, a shower episode consists of

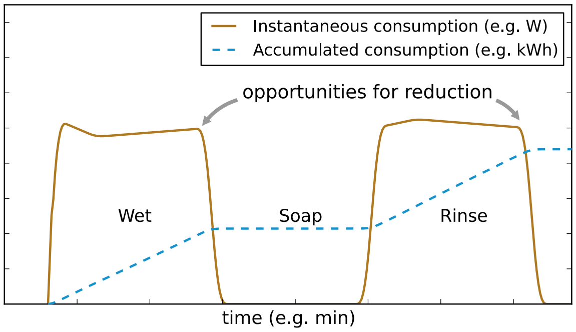


Figure 3: Illustration of a typical showering pattern: here depicted as function of time for a shower with two phases. The vertical axis depicts the instantaneous and integrated energy consumption (in arb. units).

several phases of continuous consumption, as hot water is running through the shower head. Normally, this is either

- a single phase, during which the water is just kept running the whole time,
- two showering phases, between which the water is switched off for soaping, or
- three phases, if, for example, the hair is being washed individually.

Assuming that the user sets a goal to only consume (on average less than) a specific amount of energy and water, one should obviously receive feedback once this amount is exceeded. However, it might well be the case that it is impossible for the user to just stop the water at this point, as he or she might still need to rinse off. Based on this observation, we argue that for the type of continuous consumption, it is also necessary to provide a continuous feedback and not to reduce it to a limited number of states, as it was done, for example, in the case of Upstream's ambient feedback system, which is based on a traffic light metaphor [7]. Therefore, a feedback system should not only

(i) clearly indicate the recommended ending of one phase, but also

(ii) exhibit enough structure, and therefore orientation, *during* each phase, so that the user can easily estimate his or her current consumption.

Practically, it needs to be decided what display quantization will be fine grained enough to both stimulate the perception of change and sufficiently detailed to give a sense of the absolute value.

Concerning the second requirement, a visual numerical display of one's consumption might seem the best representation, as it could always give the most detailed information. However, this would not only make it necessary to keep the display in sight for most of the time (which is both impractical and inconvenient for obvious reasons). It would also require users to become an expert in interpreting raw data values concerning their consumption – a task that many of us are not familiar with [11]. Instead, we propose that the system provides this information in a way that is easily learnable and intuitively understandable to someone who has experienced the feedback for only a few times.

4. INTERACTION DESIGN

Considering the huge dominance of visual approaches & displays that are used for *eco-feedback* (a term which is unsurprisingly often reduced to the term eco-visualization), it is worth having a look at what might be possible advantages of an approach that instead uses methods of sonification.

We argue that especially for the scenario of providing feedback *in the shower*, there are significant and considerable benefits in taking a sonification approach:

- First, the design space of a visual display is comparatively limited due to the fact that we cannot expect the user to be in full posession of his or her vision. Wearer of glasses will very likely leave them outside of the shower and the water itself (in some cases also in form of steam) might very easily interfere with a problem-free viewing of the visualization. This limited design space is also reflected in the existing (relatively simple) eco-visualizations (cf. Section 2).
- Second, it is difficult to find a place for a visual display, where it is conveniently seen at all times. For instance, in [7], a study participant noted: "Its very hard to see, you never look back behind you [while showering]".
- Third, the attention of the users are, of course, mostly focused on the main task of "taking a shower", thus making them continuously attending to an eco-visualization unfeasible. This issue is perhaps best described by a user commenting on a (numeric) visual display, saying that it "seemed to jump to a high number every time she looked at it" [7].
- Finally, putting the head under the water, as it is frequently done when showering, automatically forces most users to close their eyes, which renders a visual display effectively useless for a significant amount of time.

4.1. Using Blended Sonification

All of the above listed issues would pose no problem when instead using an auditory display. Quite the contrary, the scenario of taking a shower even expands the design space of such a display in that it allows us to use the existing environmental sound that is inevitably produced by the water falling onto the bathtub as a fundamental basis for the sound synthesis.

In fact we argue that making use of a *blended sonification*, as introduced in a companion paper [5] in this volume, is, in this particular case, superior to an auditory display using conventional methods of sonification due to the following reasons:

- Firstly, using sound synthesis that disregards the already existing sound would obviously lead to an interference between the sound that is produced by the auditory display and the "noise" of the water.
- Secondly, we have to keep in mind that taking a shower is, for most people, something relaxing [12] and thus we also want to minimize the interference of the auditory display on the act of showering itself. By using a blended sonification, we can achieve an unobtrusiveness that is adequate for an auditory display in such an environment [6].
- Thirdly, by incorporating the existing soundscape we do not discard the information that is already available via the contextualized sound.

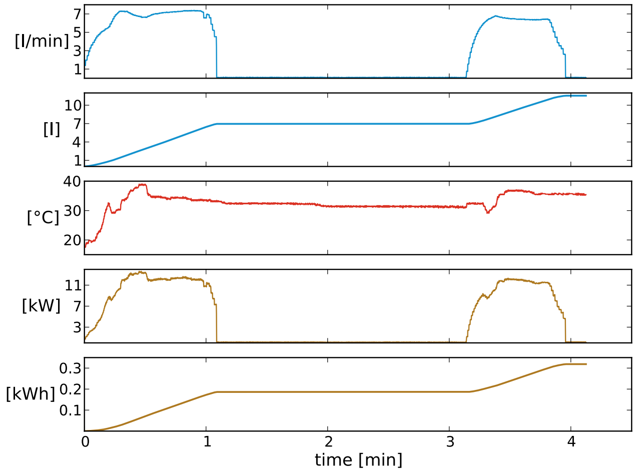


Figure 4: Real life data from the Resol Flow Sensor. From top to bottom, it shows a) the current water flow rate, b) the accumulated amount of used water, c) instantaneous temperature of the water, d) current energy consumption and e) accumulated energy consumption.

> In this case, the sound already provides information about the amount of water that is falling onto the bathtub (and which is thus currently consumed for showering).

As a result, when using blended sonification, we already have an implicit mapping of the current water flow to the produced sound.

4.2. Data

Before thinking about the actual sonification, an important question is certainly, exactly what data should be used as input parameters for it. The sensor that is used in our setup provides not only the current water flow, but also the instantaneous temperature of the water. Based on the water flow, we can additionally calculate the accumulated amount of water that has been used so far. Furthermore, we can derive from the raw sensor data both the instantaneous energy consumption and the accumulated energy used to heat the water (also cf. Section 6.2). As depicted in Figure 4, the data on energy consumption is, in its character, effectively identical to the data on water consumption. So while we decided to focus on energy consumption, a user should likewise be able to use our auditory display for a sonification of his or her water consumption.

More precisely, we are using the accumulated energy consumption as the main and primary input for our sonification, because:

- For the user, this information is the most difficult to keep track of.
- Both temperature and the water flow are, at least subjectively, directly sensory experienceable (on the skin and by listening).
- This accumulated energy value is, after all, the most relevant information for the aim of reducing one's consumption.

4.3. Showering habits

Showering habits are an important aspect we had to consider for the decision on the input data used: While some people are done in five minutes, others can easily spend half an hour under the shower.

We argue that using a fixed scale for the total consumption – as has been in [9], for example – simply can not do justice to the diverse shower habits that must be expected to be encountered in everyday life. Instead, as basis for a universally usable eco-feedback, we advocate to emphasize the *relative changes* in consumption, because these are the most meaningful to the user. This also fits very well into the theory of goal setting [13] and is the basis for our 4/5-factor approach (Section 5).

In summary, we are sonifying *relative* changes in *accumulated* energy consumption. In addition to this, we decided to use the instantaneous temperature as an additional input parameter, because temperature obviously correlates directly with the energy consumption, and the impression of felt temperature is always very subjective.

4.4. Sonification Design and the Affective Dimension

One of our first attempts at sonifying the input data (based on the contact-microphone recorded environmental sound) uses a direct mapping of the accumulated energy consumption to the frequency of a band-pass filter processing the input sound signal.

While this sonification is a comparatively simple one, it very well conveys the rising level of consumption and leads to a sonification that is fully in line with the approach of auditory augmentation introduced in [6]. However, with this continuous mapping, it is rather difficult to convey a boundary (i.e. a specific goal that has been set), and one might also argue that the result is far too unpleasant to be used in the context of taking a (relaxing) shower. Furthermore, one of our goal was to not only establish a (neutral) mapping of input data onto a specific set of sound parameters (e.g. the pitch), but to instead map the data on an *affective dimension* of sound in order to establish a subconscious association of a high energy consumption with a negative emotional response.

Since work on affective sonification is clearly in its infancy, there still is a lack of theory and established methods. Consequently, we plan to conduct further research in this direction and also want to encourage more work being done in this area.

There have been, however, relevant studies in the context of music performance (e.g. [14]), and there is strong evidence for an inherent emotional understanding of chords (i.e. the simultaneous occurrence of several tonal sounds within the twelve-tone system), for musicians and non-musicians alike [15].

Consequently, we decided to use a set of differently colored musical chords to convey an affective association. The chords used range from a major chord, which is universally perceived as consonant and harmonic, to a dissonant cluster chord based on chromatic semitones with no meaningful harmonic interpretation (cf. Table 1).

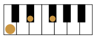
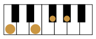
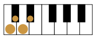
Semitones	Harmonic interpretation	Visual
0, 4, 7	major	
0, 5, 7	suspended (sus4)	
0, 3, 6	diminished	
0, 4, 6, 8	augmented (#11)	
0, 1, 2, 3	?	

Table 1: Musical chords used for the affective dimension in the sonification.

One possibility to establish the above chords is by processing the environmental sound through multiple (narrow) band-pass filters. This also would lead to a sonification consistent with the approach of auditory augmentation.

Pure filtering, however, provides only limited design opportunities compared to the possibilities in computer sound synthesis. To explore this space for future extensions, we decided to couple synthesized sound tightly to transients in the source sound of water falling into the bathtub. This creates a blended sonification according to the framework introduced in our companion paper [5] as follows: Interpreting the sound of the water drops falling onto the bathtub as impulses of differing energy/loudness, we use these impulses for triggering sounds that are pitched according to randomly selected tones of a musical chord corresponding to the actual accumulated energy, relative to a personal goal. To stay in musical terms, this ultimately results in a sound-induced continuous arpeggio. Note that in addition to the "primary" chord tones shown in Table 1, we also transpose the respective tones by n octaves, i.e. we construct a "chord-scale", which we base the arpeggio on.

Although the general assumption is that representing a rising temperature with a rising pitch is the "natural" choice, it has been shown that preference for this polarity is not a very strong one [16], and, in our current implementaion, we made the design decision to instead represent a high temperature with a low-pitched sound, since the higher pitched arpeggios manage to evoke thoughts of coldness, while the lower-pitched ones make a more "energetic" impression. While we felt that the use of such a metaphorical mapping is, in this case, a more intuitive one, this certainly requires further evaluation.

We also discovered that the harmonic impression is fairly susceptible to *arbitrary* changes of pitch in that these can easily mask the changes in chord type. However we managed to retain the chord's harmonics by transposing only *within* the corresponding chord scale.

The last but not least design decision was to make use of a dB-based fade-in of the sonification at the beginning of a shower in order to allow for a smooth and thus unobtrusive transition from the initial sonification-free state.

5. THE RIGHT PACE OF CHANGE: THE 4/5-FACTOR PRINCIPLE

Goal setting has long been identified as being highly beneficial to achieve behavior change (e.g. [17, 13]). However, as the large majority of interventions in sustainable HCI are quite short, there has been little consideration about how to actually achieve a *lasting* reduction in consumption.

We argue that – just like when losing weight – a change in behavior should not be something to be forced in a short amount of time, but instead must occur in a slow pace, so that the danger of becoming frustrated or switching back to the old behavior is reduced [18]. This is supported by recent work in empirical psychology, identifying a *continuous and steady* progress as one of the biggest motivating factors, even if it consists only of small "wins" [19].

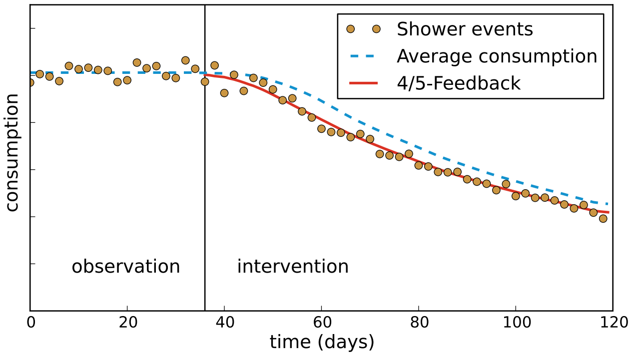


Figure 5: Illustration of the $\frac{4}{5}$-factor approach: the consumption goal is adaptively set to $\frac{4}{5}$ of the actual moving average, causing a steady and mild feedback towards reaching an ultimate goal.

However, we also have to consider that different people have vastly different habits of showering, which means that we have to effectively "meet" them at their individual current level of consumption. Following this thought, we here propose our "$\frac{4}{5}$-factor approach" as a guiding feedback for a slow but continuous reduction in consumption, which is illustrated in Figure 5. It is based on calculating a moving average of the current consumption (which needs to be observed initially for a few number of shower episodes), and which is then used to set an intermediate goal

$$g_i = \upsilon \cdot \mathrm{MA}_c, \quad 0 < \upsilon < 1, \tag{1}$$

where MA_c is the moving average of the current consumption, and υ defines a (comparatively large) fraction of this value as an immediate goal, e.g. $\upsilon = \frac{4}{5}$.

As a reduction in consumption automatically leads to a (slightly) reduced moving average (which in turn influences the intermediate goal), a gradual increase in goal difficulty is achieved. However, since a consequent adhering to these intermediate goals would lead to a consumption level close to zero, the above formula must be slightly changed by implementing a given long-term goal:

$$g_i = \upsilon \cdot \mathrm{MA}_c + g_L \cdot (1 - \upsilon), \tag{2}$$

where g_L is either a pre-set lowest level of consumption or a value that can be set by the user as a measure of difficulty.

The size of the averaging window is an additional parameter that can be set to determine the desired adaptation rate: A smaller window translates into quicker adaption to the user's behavior and thus to a faster rate of change over iterations. The inverse window size thus roughly corresponds to the users' ambition to change. Note that when dealing with several phases of consumption, this principle can be applied to each phase individually.

6. IMPLEMENTATION

6.1. Technical Setup

Figure 1 shows the overall (high-level) hardware setup that has been used in our experiments. As the user is taking a shower, he or she will inevitably produce a sound of water falling onto the bathtub – a sound that most of us know and are accustomed to. With the bathtub as a resonating body, this sound is not only audible for the person in the shower, but can also be captured by a contact microphone (we are using an AKG C-411) and this signal is used as input for our sonification.

For the consumption sensing, we installed a sensor that measures both the instantaneous water flow and the temperature of the water. More specifically, we are using a Resol Grundfos

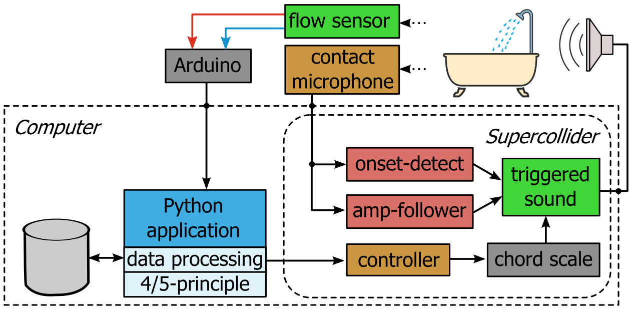


Figure 6: Overall architecture for the transient-triggered sonification.

VFS 1-12 l (Figure 8), which outputs these values as analog voltage signals that are read out and sent to a laptop with the help of an Arduino board [20]. The (now digitized) measurements are captured and evaluated by a python application, which in turn controls a SuperCollider server via OSC.

As the core element of our framework, the SuperCollider-based sound synthesis effectively processes the water drop audio signal on the basis of the (post-processed) sensor readings (also cf. Figure 6). Finally, the audio output is projected to the user using off-the-shelf loudspeakers.

A disadvantage of the Resol sensor that we found is the surprisingly large latency of the flow sensor, which sometimes led to slightly odd results: While the sensor almost immediately detects a water flow, its readings need up to 15 seconds to converge to the correct value (Figure 4a). When switching the water off, latency is around 7 seconds. Note that our proposed modifications to the technical setup would also eliminate these latency problems (cf. Section 9).

6.2. Determining the energy consumption

Besides the water consumption, which can be calculated directly from the instantaneous flow measurements via numeric integration over time, in our setup it is also possible to approximate the energy that has been used to heat the water. For that the effective heat capacity of water $c_m = 4.1813$ kJ/(kg·K) must be used to calculate the current energy consumption W (i.e. the power to heat the water in Watts)

$$W(t) = c_m \cdot (T(t) - T_c) \cdot \mu, \tag{3}$$

where μ is the current mass flow rate and $(T(t) - T_c)$ denotes the difference between the current (at time t measured) temperature $T(t)$ and the temperature T_c of cold/unheated water.

7. INTERACTION EXAMPLES

In order to provide an impression of a real-life usage of our auditory display and to illustrate the differences between the various sonification approaches, we recorded several sound examples[1]. Additionally, we have made available both the raw output of the contact microphone and the ambient sound, as picked up by a dynamic microphone.

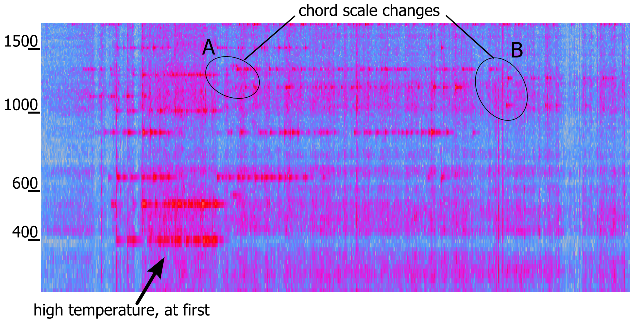


Figure 7: Spectogram of the first minute of sound example S1.

Sound examples S1 to S4 are all based on the same auditory input. The corresponding water flow and temperature data can be seen in Figure 4. Since the sonification does not change between the two showering phases, we have cut out the (rather uninteresting) middle part of each recording in order to focus on what happens during the two actual showering phases. Also note that the volume of the sonification was set to a relatively high level in order to make the sonification part more salient for the listener. For practical use, a lower volume would be chosen.

As described in Section 4.4, sound example S1 incorporates a band-pass filter, whose frequency is controlled based on an increasing (accumulated) consumption. In sound examples S2 (using the same audio and consumption data), we implemented our affective chord scale by using multiple narrow band-pass filters. Note that we cyclically faded in (and out) additional overtones within each chord segment, in order to achieve a more continuous feedback. Also note that the water temperature was not mapped to any sound parameter in this example. Sound example S3, in addition to also using the same affective chord scale, incorporates transient-triggered sounds, and scale-restricted transposing based on temperature changes.

Finally, sound example S4 is very similar to S3, with the only difference being that instead of employing purely synthesized triggered sounds, we are using a number of recorded samples (of water glass clinks), which, to our opinion, sound more lively and natural. Figure 7 shows a log-frequency spectrogram of S4 of the first showering phase (approximately one minute), where some of the sound characteristics can also be observed visually: After the first seconds, with only ambient sound audible, the sonification slowly fades in, initially indicating a very low water temperature. A pitch-drop (still within the first chord-scale) then identifies a rising water temperature, after which it is regulated back and slowly decreases over time.

At 33 seconds into the sound example (label A in Figure 7), the chord scale changes, indicating a rising level of consumption. This happens as well after 56 seconds (label B) and, in the second showering phase, at 01:41, after which the scale becomes the most disharmonic nearly at the end of the shower (at 02:06), which means that the user has missed his goal by only a little. At the beginning of the second phase, the small variations in temperature are, again, clearly audible.

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[1] The discussed sound examples can be found under: `http://www.techfak.uni-bielefeld.de/ags/ami/publications/HH2013-ISF/index.html`

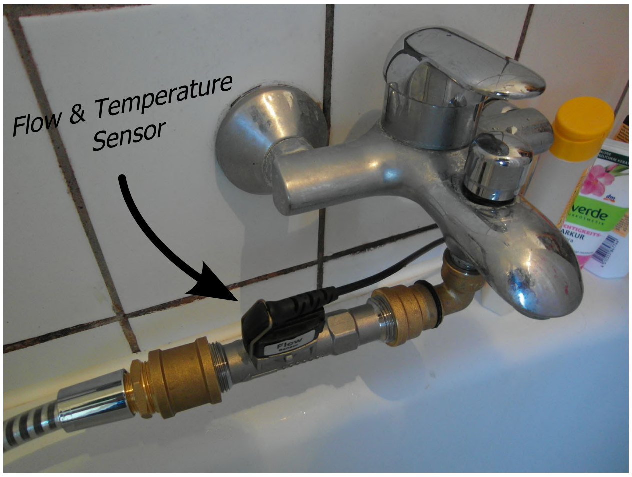

Figure 8: Picture of the installed Resol Grundfos flow sensor in the circuit between tap and shower head.

8. DISCUSSION

With the InfoDrops sonification system, we have introduced a novel auditory ambient information system. Our method differs from the state-of-the-art, which are mainly eco-visualization systems, in several aspects.

First, our approach differs by offering information in auditory form, whereby we overcome the problems of visual feedback, particularly in the shower where the eyes are partly closed, no glasses are worn, and the head is oriented towards other places than where the display is. Without doubt, sound has many advantages in this environment. However, it also has some drawbacks. For instance that the sonifications fail to convey absolute values. In an early design brainstorming, we have considered explicit verbal level, such as a voice saying ”20%......30%.....”, or a countdown. While this would be more precise in terms of information, it would also be very explicit and remind the user of the consumption itself. Addressing cognitive processing, this path requires some cognitive detours (e.g. via language processing, interpretation, etc.), making the display more obtrusive. We speculate that the difference between our ambient information system and such an audible, consumption-dependent countdown is probably similar to the difference between a numeric and an ambient light visualization.

Yet all people are different, and some users may prefer a more explicit functional display over an ambient awareness system. We think that for practical deployments in hotels or households we could integrate many different ‘information themes’ that users can select. Fortunately, all different auditory displays can be supported with the same hardware (a loudspeaker), whereas for ambient visual displays each different display would require an own dedicated physical realization.

Beyond uni-modal systems, multi-modal information systems that manipulate audiovisual cues may be the most effective. This, however, needs to be checked by designs and evaluated with studies.

Second, our approach differs by encoding the information in a sequence of affective sounds so that – even without being familiar or having learned the display – users will be able to understand that a situation is getting “worse”, as there is a movement towards a less positive/harmonic state. Concerning the affective sounds, we have considered alternatives such as the transition from ‘giggling’ to ‘screaming’ voices (but to be honest this was never a serious idea), or sounds that range from up-chirps to down-chirps (the latter resembling sighing). While such articulated patterns are perhaps quite affective, they can be also irritating and induce an aversion against using the system. Physical interaction sounds, such as contact sounds, are most natural and occur anyway in this environment. Adding sounds in this dimension introduces the least break with expectations.

Third, our approach binds the sonification tightly to interaction sounds that occur anyway. This is not a completely new idea, but so far little exploited in ambient information displays. We expect our auditory display to be much more acceptable for users and causing less annoyance than any other system where sound has no coherence to physical activity in the immediate environment. This, of course, needs validation, and studies on this topic are on our agenda.

Fourth, our system goes beyond state-of-the-art methods by introducing a systematic approach to smoothly change the goal so that users can establish new habits, i.e. that a new behavior becomes normal. To our personal observation, the longer a behavior is being practiced, the more it becomes normal; the normative power of repetition is quite high. We assume that a steady 4/5 reduction over 50 iterations would for most persons be slow enough to establish a new behavioral default. The verification requires longitudinal studies, and thus long-term use of a system. A major problem of such a long-term study is, in this case, however, that our shower habits are also modulated by seasonal factors (for instance in summertime we may even shower with cold water). Studies that requires so many episodes that the seasonal changes interact with the effect are very difficult to conduct.

While the users probably adapt their behavior to the available system, they also might become dependent on its feedback. This is an important question: how does a changed habit develop once the feedback system is deinstalled? Without retention effect they would (at some time constant) fall back into their old habits; or they might just keep their newly acquired habit. This is an open question which can only be answered by studies.

From a practical point of view, our system – as probably most new inventions – has many loose ends: how can the system adapt to variations in shower style: for instance, if users tend to shower with one or two phases depending on their mood. How can a system personalize the feedback if the shower is used by several people, e.g. family members. A login procedure – to give a commitment – would be rather explicit and thus conflict with the aim of being an ambient and unobtrusive interface. However, cameras for face recognition are likely not accepted in this environment. A scale to recognize the person from the weight seems appropriate, yet this is also difficult to integrate in existing showers. For now we think that the single-household is the most straightforward target, which effectively circumvents the login problem.

9. CONCLUSION

This paper introduces a novel auditory display that tightly couples physical interaction sounds to task-specific auditory representations. As a second important contribution, it describes the 4/5-factor approach, which provides a new perspective on habits and habit change.

We hope that the paper can serve as starting point for a discussion of how the topic of energy-awareness can be addressed through the use of auditory displays. Also, it adds to the notion of a sound's affective dimension as further means to guide a user's attention and to convey an additional layer of information.

Focussing on these new concepts, we certainly see the need for practical evaluation, which we aim to conduct as future work. Furthermore, a refinement of the technical implementation can certainly improve the practical feasibility of the auditory display: another direction of future work could be the integration of the whole hardware setup into a smartphone that receives information on consumption from a central smart meter.

Concludingly, we can say that – although further research is certainly neccessary – we see great potential in auditory displays providing guidance towards a less resource-intensive lifestyle.

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