RainSense: Exploring the Concept of a Sense for Weather Awareness

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Abstract
The amplification of human senses has been in the focus of contemporary research for the past decades. Apart from the replication of human organs, the functionality of the human body has been enhanced. While many approaches aim to augment existing sensory channels, our research purpose is to explore the creation of a new sense, namely a sense for weather awareness. For this, we present our concept which is based on the presentation of thermal stimuli. Hence, we initially explored the perception and suitability of thermal feedback stimuli to communicate weather information, and particularly precipitation in an experiment comprising 16 participants. From the qualitative and quantitative results we derive important findings helping us to advance the realization of our concept in future research involving a field study to further evaluate the creation of a sense for weather awareness.

Author Keywords
Augmented senses; sense enhancement; wearable computing; thermal feedback.

ACM Classification Keywords
H.5.m [Information interfaces and presentation (e.g., HCI)]: Miscellaneous

Introduction and Related Work

Augmenting human senses lately received considerable attention in human-computer interaction [8]. For example, research showed how to increase human‘s visual capabilities [1]. Researchers are also making efforts to rebuilt human sensory organs, such as the nose [9]. Accordingly, there has been put a lot of effort into the development of hardware helping humans to create new senses. Kasahara et al. [6], for example, built a system for creating a novel sense enabling users to see the first person views of other in combination with their own using a head mounted display. Likewise Fan et al. [2] presented a similar approach and developed a wearable device that enables users to be aware of what is happening behind their back. All these works aim at providing a benefit to the users' everyday life by increasing their capabilities and efficiency to solve upcoming challenges.

Thermal Feedback

Thermal feedback is a widely known and successfully applied type of feedback used in prior work [10, 11, 12, 13, 14]. Thermal stimuli, particularly warmth and coldness, can be perceived differently and are vulnerable to subjective interpretations [11]. For example, Wilson et al. [12] revealed that warm stimuli are perceived more positive than cold ones when they are mapped to emotions. The results of Suhonen et al. [10] show that cold stimuli were more favourable to their participants. In another study focussing on mobile devices, Wilson et al. [14] confirmed that cold stimuli are easier to perceive and are more comfortable when being presented at the user‘s palm. Additionally, when using thermal feedback, the environmental conditions influence the perception of the stimulus [4].

While the perception of continuous thermal stimuli presented at the palm has been explored by Halvey et al. [5], we focus on the association of thermal stimuli and weather information. Further, conceptual metaphors such as "She was burned out after" or "He was frozen at place" have been explored in prior work [7]. This marked an initial start for exploring interpretations of thermal stimuli, which we extend to the interpretation of thermal stimuli with regard to weather information in our work.

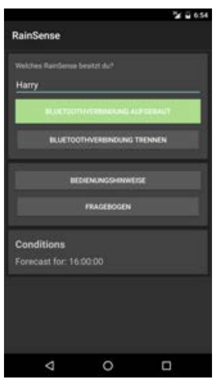
In this work, we explore a novel application scenario for thermal feedback in which we use thermal feedback as an implicit mean to communicate weather information – thus, we aim to create an artificial sense for weather awareness. We present our concept of communicating weather information and introduce our prototypical device that provides thermal feedback. For the realization of this concept, we report on an experiment on the perception and suitability of thermal feedback to communicate information on precipitation.

Creating a Sense for Weather Awareness

The main idea of our approach is to communicate weather information, that is in our case information on precipitation. We present a stimulus prior to the actual start of precipitation. This stimulus should be implicitly perceived by the user and, thus, act as a novel artificial sense that is automatically linked to the weather condition. Since we aim to provide an implicit feedback that should use as little cognitive resources of the user as possible, we identified thermal feedback as an appropriate feedback mean.

Thermal feedback – mainly presented through Peltier elements – can slowly change the temperature and, therefore, make the user feel warm or cold without putting too much emphasis on the feedback itself. Research explored several feedback positions for thermal feedback.

(a) Our hardware prototype being able to deliver warmth or coldness, respectively at the exterior and interior side of the wrist.



(b) The user interface of our Android application receiving weather information based on the user's GPS location.

Figure 1: Prototype and Android application built for testing the concept of communicating weather information implicitly through thermal feedback.

Since we aim at an unobtrusive way of providing feedback, we chose the user's wrist which can be regarded as the main location when providing feedback with wearables i.e. fitness bracelets or smartwatches. At the user's wrist, the veins transporting the blood to the heart are located close to the skin. Thus, thermal feedback can, with only a small change of temperature, create a feeling of temperature alteration in the user's perception.

Prototype

We developed a physical prototype (cf., Figure 1a) that is connected to an Android application and capable of providing thermal feedback to users. The device is based on an Arduino Pro Mini, which controls a Peltier element through a half H-bridge driver. Peltier elements are semiconductors capable of creating the Peltier effect, that is the heating or cooling of a surface when applying voltage. Thus, the prototype is able to respond to commands from an Android application (connected via Bluetooth) and provide temperature feedback to the user. The Bluetooth interface allows to control the feedback direction (i.e., cold or heat), the intensity of the stimuli, and their duration.

Android Application

The Android application (see Figure 1b) uses the Weather Underground API [1]. This service hosted by the National Weather Service's makes data from the National Digital Forecast Database accessible and provides weather information based on data from weather stations, meteorology and private persons. Using this API and the current GPS location, the application can get information on upcoming precipitation. As soon as an upcoming precipitation is detected, the application triggers a thermal stimuli. To understand how such a stimuli should be designed, we extracted information from related work and conducted an experiment exploring user's perception of the feedback with regards to precipitation and weather forecast in general.

[1] https://www.wunderground.com/

Evaluating Thermal Stimuli for Precipitation

By evaluating thermal stimuli we investigate the following research questions:

(RQ 1) *Are thermal stimuli suitable to provide feedback on weather information?*,

(RQ 2) *How should thermal stimuli look like to communicate weather information?*.

To answer these questions, we conducted an experiment involving 16 participants. We asked them to rate different thermal stimuli with regards to their applicability in our application scenario as well as provide qualitative feedback.

Thermal Stimuli

For this experiment, we used the wearable prototype to elicit different thermal stimuli. As thermal stimuli, we compared 16 different impulses; four warm and four cold stimuli, being applied individually to the interior and exterior side of the wrist and four cold stimuli being also presented at these two different wrist positions. Both stimuli, cold and warm presented four levels of intensity (Level 1-4), resulting in variations respect to the room temperature of about 7,9,11, and 12 Celsius degrees.

To assess the subjective pleasantness, we asked our participants to rate their level of comfort on a 5-point Likert item ranging from 1(=very unpleasant) to 5(=very pleasant). Further, we posed the following two questions in a subsequent semi-structured interview to gain qualitative feedback:

(1) *Do you think that the perceived cold/warm feedback would be recognized in your daily routine?*

(2) *The given feedback is to be associated with forecasting upcoming weather conditions. Which weather condition could be forecasted when cold/warm feedback is transmitted?*

Participants and Procedure

In total 16 participant ($M = 22.9$, $SD = 1.63$ years) consisting of six females and 10 males took part in the user study. We recruited the volunteers via student mailing lists of our institution and we remunerated them with sweets.

Before the procedure started, we explained each participant the purpose of the experiment and the sequence of events mentioning that we would gather their subjective feedback on the presentation of thermal stimuli for communicating weather information. After they read and signed the consent form, we attached the wearable prototype to the non-dominant hand of the participant. Afterwards, we presented each of the 16 stimuli for 10 seconds and the participants directly rated the pleasantness after each of the stimuli. We balanced the order of the stimuli using a Latin square design. The user study approximately took 12 minutes. After we presented all stimuli, we asked the two additional questions. This study procedure had been approved by the Ethic Committee of our institution.

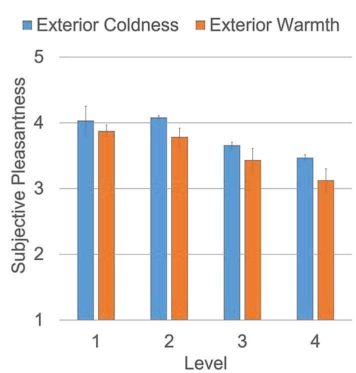


Figure 2: The results for the overall comparison between cold and warm stimuli over both positions, the exterior and interior side of the wrist.

Quantitative Results

Our results show that coldness has on average been perceived more pleasant for both wrist positions in comparison to warmth (cf., Figure 2). Further, the mean values over all levels indicate that cold stimuli have been preferred regardless the position they have been presented at (cf. Table 1). With respect to the four different temperature levels the first two levels have been perceived as most agreeable as suggested by the mean values depicted in Table 1. An overall comparison over all presented stimuli revealed that the first level has been rated best with 4.19.

	Interior Side		Exterior Side	
	Coldness $M(SD)$	**Warmth** $M(SD)$	**Coldness** $M(SD)$	**Warmth** $M(SD)$
Level 1	4.19 (0.75)	3.81 (0.91)	3.88 (0.96)	3.94 (0.93)
Level 2	4.06 (0.85)	3.69 (0.79)	4.10 (1.12)	3.88 (0.89)
Level 3	3.63 (0.96)	3.31 (1.08)	3.69 (0.95)	3.56 (0.96)
Level 4	3.50 (1.10)	3.00 (1.27)	3.44 (0.95)	3.25 (1.07)
Overall	3.85 (0,33)	3.45 (0,37)	3.78 (0,28)	3.66 (0,32)

Table 1: Means and standard deviations for the subjectively rated pleasantness over all participants according to the four different levels, respectively for warm and cold stimuli presented at the interior and exterior side of the wrist.

Qualitative Results

Regarding the semi-structured interviews, the participants described the cold feedback as *'interesting'* and *'not disturbing'*, while they associated *'pain'* with the warm stimuli. One participant stated *'I rather like it if the safety belt in a car is cold instead of warm when it is blazingly hot'*. Moreover another one referred to malfunctions that are often associated with warmth saying *'The cold feedback gives an extraordinary feeling which cannot be found in everyday products in contrast to warmth. Warmth is often a sign of malfunctions or undesired effects, such as smartphones becoming too hot or a notebook on the lap heating up'*. One participant even talked about *'fear'* due to the concentration of warmth in a small area.

According to the first question *'Do you think that the perceived cold/warm feedback would be recognized in your daily routine'*, all participants except for one said that they would recognize the cold feedback in their daily routine. For the warm feedback, only nine interviewees affirmed this.

For the second question *'Which weather condition could be forecasted when cold/warm feedback is transmitted?'*, we got confirming responses. All participants agreed that the warm feedback was associated with weather changes, the majority said that it signified good and warm weather, even heat. For the cold feedback, we inferred from the interviews that it was associated with precipitation such as snow, rain, or hail. Further, participants stated that they thought of bad and cold weather, likewise weather changes.
In addition, the interviews revealed implications for the everyday life. For example, some interviewees said the feedback on weather information could affect their behaviour when being presented in the mornings. They imagined it to be helpful when picking clothes or when deciding on which mode of transportation to use for going to work, university, etc. Another idea mentioned by a participant was to combine the feedback with smart home devices and therefore integrate the feedback into the home environment.

Finally, we wanted to know whether they considered the implicit feedback to be beneficial. Hereby, our participants had incoherent opinions. Whereas half of the interviewees would appreciate to be notified about weather changes without having to look on the smartphone or searching actively for them, the others argued that having information about the weather would not change their daily routine.

Findings

From the results we derived the following key findings providing first insights in the exploration of the suitability and perception of thermal stimuli to communicate weather information:

- Cold stimuli with a variation of 7 Celsius degrees to room temperature and being presented at the interior side of the wrist are perceived most pleasant.
- Cold stimuli are associated with precipitation and therefore imply unpleasant weather changes.
- Depending on the use case, implicit feedback on weather information is perceived as beneficial.

We acknowledge that the perception of thermal stimuli is vulnerable to subjective interpretation [11] as can be also seen with regard to associating thermal stimuli with emotions [12]. However, this subjectivity is difficult to overcome since 'the same stimulus can cause a greater degree of warming or cooling in one subject than another' as Gray et al. [3] pointed out in a large investigation of thermal stimuli thresholds. However, we obtained these key findings from the results, which are also supported by Wilson et al. [13] stating that warm stimuli are perceived less comfortable. We believe these insights yield important implications for our future research activities. Since Halvey et al. [4] found that thermal stimuli are perceived differently in distinct environmental context and can be harder to recognize, it might be interesting to investigate whether users would prefer other stimuli for communicating weather information when being outside.

Future Work

From our findings based on a preliminary evaluation of our approach, we could infer promising insights for an experiment validating our concept in the wild in the future. Further, we will also focus on the exploration of the feasibility to establish a learned connection between the thermal stimuli and precipitation and their effects on the user's behaviour.

Conclusion

In this work, we introduce our concept of how to develop a sense for weather awareness. For this, we build a mobile wearable prototype being able to deliver thermal feedback.

By the exploration of thermal stimuli in an experiment, we could show that cold stimuli are suitable for communicating weather information, and in particular referring to precipitation. Based on our findings we derived from the quantitative and qualitative results, we addressed our future work plans to test our concept in an in-the-wild user study.

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