Comparing Thermal and Haptic Feedback Mechanisms for Game Controllers

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Abstract
We investigate the use of thermal feedback, i.e. the feeling of warmth and cold, as an output mechanism for hand-held device user interfaces (UIs). In a prototype implementation, we enhanced a console game controller with thermal elements, positioned under the user's fingertips. The prototype was evaluated using a simple video game, where the user was required to locate targets based on output cues. In a user study (n = 21) the performance and user experience of using visual, vibrotactile and thermal forms of feedback in the game were compared. Our salient findings suggest that thermal UI feedback is suited for presenting ambient information cues or creating an atmosphere.

Author Keywords
Thermal feedback; gamepad; vibrotactile feedback.

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

Introduction
Haptic features of mobile interaction devices are an essential part of their usability and user experience. The form factor defines the grip ergonomics, and

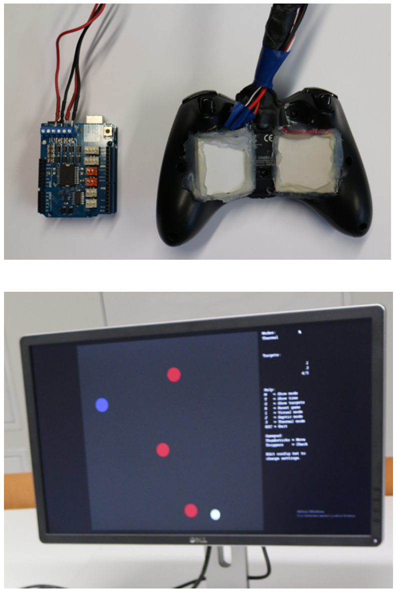

Figure 1: Equipment in the user study. Top: Xbox Gamepad augmented with Peltier elements. Bottom: Screenshot of the Hide-and-Seek game.

buttons and other input components should not only be reachable but also easy to locate in eyes-free interaction. Haptic modality is often used to provide the user with feedback of input actions, and e.g. with mobile phones, vibrotactile feedback is an essential design parameter [5,11]. The interaction design space when touching an object however extends further than just the feeling of tactile and kinesthetic aspects. When touching an object, we also feel the temperature of the object. Thermal feedback, i.e. sensing warm and cold, has so far gained comparatively little attention among HCI research.

In this paper, we explore thermal feedback as a feedback mechanism for handheld devices in a gaming context. While vibrotactile feedback is already quite popular as a feedback mechanism in gaming, thermal feedback has so far been neglected. Whereas earlier works on thermal feedback have focused on conveying emotions [1,10], or the effect of clothing and environmental factors on thermal feedback elements [2,4], we present a comparative user study on visual-, vibrotactile- and thermal feedback. To assess the abilities of the thermal feedback, we created a small hide-and-seek game (see Figure 1) that allowed the incorporation of visual-, vibrotactile-, or thermal-feedback as active game elements, and evaluated and compared the correspondent experiences.

Related Work

Thermal feedback has been much investigated from the physiological point of view, of which [6] gives a good overview. Thermal feedback has also been evaluated for a variety of purposes. One of the first investigations presented was the the Hiya-Atsu system, that enriched a mouse with thermal feedback [8]. This is very similar to our approach as it incorporates thermal feedback into a known interaction device. Halvey et al. showed the feasibility of enriching visual information designed to evoke emotional responses with thermal stimuli [3] and even in neutral images [1]. Wilson et al. showed that there is a strong agreement in the interpretation of thermal stimuli [13]. Even though the interpretations are coherent, only a limited number of emotional expressions can be conveyed [12]. Suhonen et al. [10] have conducted an investigation on user experience with thermal feedback in comparison to tactile feedback, but did not include a controlled performance test for the system. Löchtefeld et al. analysed the user experience of a tablet that included thermal feedback during media consumption [7]. All these investigations highlight the possibilities of thermal feedback for enhancing media in an ambient way. This led us to investigate the phenomena in a gaming scenario as an active game element and not only ambient feedback which has, to the best of our knowledge, not been done before.

Thermal stimuli as a means of interaction on mobile devices has been explored by prior art. Besides investigating the suitability of areas of the body and their receptiveness for thermal stimuli [15], Wilson et al. have presented methods to convey information using thermal feedback [14]. Halvey et al. investigated the effect on clothing on the perception of thermal stimuli [4]. As their results showed that the presence of clothing requires higher intensity thermal changes for detection we decided to use direct stimuli of the skin for our work. Furthermore it has been shown that ambient temperature has a significant impact on people's ability to detect stimuli [2], but as our approach is set for an indoor gaming scenario this should not be a factor in our evaluation.

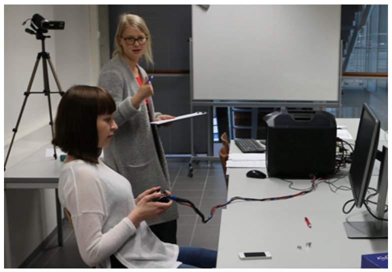

Figure 2: Setup of the user study.

Preliminary User Study

The goal of our preliminary study is to investigate the capabilities and experience of using thermal feedback as an active game element in comparison to visual- and vibrotactile feedback. Active game element in this case means that the user has to react to the given feedback to be successful in completing the task, as compared to ambient game elements or feedback, which aim only to increase immersion. For this we created a simple Hide-and-Seek game that allowed us to exchange the different modalities easily.

Prototype Implementation

Our prototype consists of an XBox 360 USB controller, two Peltier elements (TEC1-12706[1]) and an Arduino Uno with a Motorshield. We chose the XBox 360 controller as it already provides a good ergonomic design and vibrotactile feedback through two vibration motors. To include the Peltier elements into the XBox controller we used a power tool to remove two rectangular sections on the back. The Peltier elements, which were equipped with thin heat-sinks on the side touching the controller, were attached using hot-glue. This allowed us to remodel the ergonomic form of the XBox controller. The Peltier elements were located in a way that they were positioned under the upper part of the fingers and the finger tips. This approach targeted to alter the ergonomic form of the controller as little as possible, the size the Peltier elements and heatsinks prohibiting positioning them closer to the thenar eminence, which is known to have better thermal reception [15]. Using the Arduino Motorshield provided an easy way to switch the polarity of the Peltier elements to create hot as well as cold stimuli. We connected a lab power supply to the motorshield to provide enough power to heat up and cool down the Peltier elements as rapidly as possible.

To test the prototype in a gaming context, a simple Hide and Seek game was implemented using the Unity 3D game engine. In the game, the player played the role of a seeker, controlling a white sphere in a rectangular shaped game area, visible on a PC screen (Figure 1). The player's task was to find five hidden, sphere-shaped target objects that could be either of type ”cold” or ”hot”. The position and type of targets was randomized, and normalization was applied. Only one target at a time was active, meaning the player must find that target before the next one was generated in the game area. Game events, including the start and end of the game, game mode, player positions, made guesses and found targets were logged with time stamps.

When the game started, the player – represented by the white sphere – started moving around the game area going either left, right, up or down using one of the joysticks of the prototype controller. To guess the position of a target, the player pushed one of the trigger buttons on the prototype controller. If the white sphere overlapped with the hidden target when guessing, the target became visible and remained so until the next round of the game. Depending on the type of the target, its color was either red (”hot”) or blue (”cold”). In case the player did not overlap with the target when guessing, but was in close range, the player was provided with feedback, hinting to the proximity and type of the target. The closer the player was to the target, the stronger the feedback. The game

[1] http://www.hebeiltd.com.cn/peltier.datasheet/TEC1-12706.pdf

ended when the last target was found and all the targets were visible.

Conditions
The basic game mechanic was the same in all three conditions: finding five (5) hidden circles at the game field, see Figure 1. The three conditions for our experiment were, *visual*, *vibrotactile* and *thermal.* In the *visual* condition the user had to find the hidden circles with the help of visual cues. The cursor changed color dynamically, and the closer the user was from the hidden circle, the more intense the color (red or blue) was. For the *vibrotactile* condition the closer the user was to the hidden circle the more intense the vibration in the gamepad was. To differentiate "cold" and "hot" objects, the former ones were hinted by alternating vibrations with the left and right motors, whereas the latter ones were indicated by a constant vibration in both motors. Lastly, for the *thermal* condition, the closer the user was from the hidden circle, the larger the temperature differential.

Procedure
The study was held in a laboratory setting (see Figure 2) and the ambient room temperature was stable at 22.6°C. At the beginning of the evaluation, the purpose of the study was explained, and a consent form and background questionnaire were completed. Participants completed three tasks. Before each task the participants were instructed and before the first task the test facilitator demonstrated the game mechanics with the controller and the visual cues activated. After each condition the participants completed a NASA Task load index form [9]. To avoid bias, the order of the conditions was counterbalanced. After all three conditions, the participants completed a post-test questionnaire about positive and negative issues of thermal feedback, and provided suggestions on improvements and use cases. During the test session, the participants were encouraged to think aloud, and the test facilitator noted the comments and observations. The game logged player's movements and task time for each condition.

Participants
The study was conducted with 21 participants (11 female) aged between 21 and 41 years (median 24 years). Participants were recruited via social media and *in situ* at a university campus. All participants reported having a normal or corrected-to-normal eyesight, normal color vision and a normal sense of touch, and all but two (19/21) had earlier experience with computer or console games. The temperature of the participant's fingertips and palm were measured with an infrared thermometer. The skin surface temperature between participants varied from 22.0°C to 34.4°C (*M*=26.9°C *SD*=3.8) at fingertips and between 28.0°C and 35.6°C (*M*=31.4°C, *SD*=2.1) at the palm. The average length of the test session was 30 minutes.

Results
Performance
Considering the time and movement distance required to complete the task (Figure 3 and Table 1), a Kolmogorov-Smirnov test indicated that the data was not normally distributed, hence non-parametric analysis was applied. Friedman tests for task time and distance indicated significant differences between the cases. Post-Hoc Wilcoxon signed rank tests, with a Bonferroni corrected significance level of significance level set at $p < 0.017$, indicated that the time taken and distance moved in the thermal condition were significantly larger

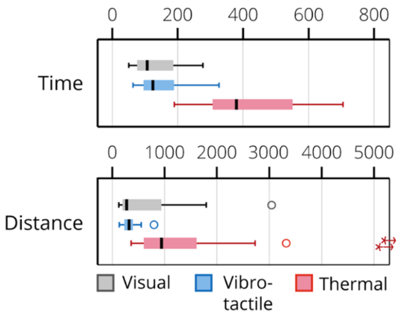

Figure 3: Time and distance comparison between the different feedbacks (Visual-, Vibrotactile- and Thermal)

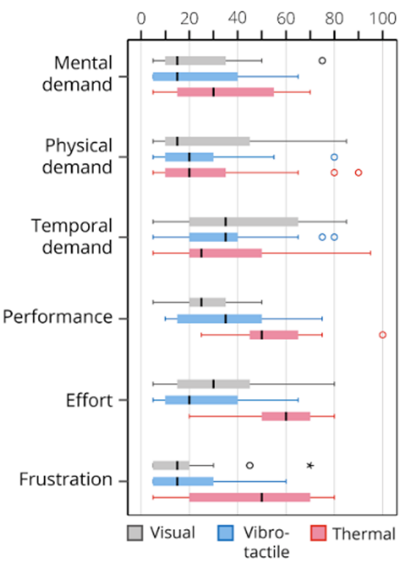

Figure 4: NASA TLX results of the user study

than in the other conditions. No significant difference between visual and haptic conditions was noted.

	Time (s)	Distance (units)
Visual	139 *SD* = 76	670 *SD*=752
Vibrotactile	148 *SD*= 77	321 *SD*=152
Thermal	416 *SD*=160	1684 *SD*=2049

Table 1: Mean time and distance to complete the test task in each condition.

Thermal feedback was the least efficient and most difficult, based on both measured and observed data. NASA TLX scores (Figure 4 & Table 2) show that the workload of thermal feedback was highest on mental, performance, effort and frustration subscales. This finding was supported by qualitative comments, e.g. *"Thermal feedback doesn't inform in the same level of detail as the other feedbacks."* (#11). Seven participants (#2, #3, #6, #8, #10, #11, #17) explicitly stated that the vibrotactile feedback was the clearest and the fastest way in the context of the study tasks: "*The stopping of the vibration was the easiest to notice"* (#2).

	Visual < Thermal	Vibrotactile < Thermal
Mental	p = .007 (0.42)	p = .003 (0.45)
Performance	p < .001 (0.54)	p = .003 (0.45)
Effort	p < .001 (0.55)	p < .001 (0.46)
Frustration	p < .001 (0.54)	p < .001 (0.57)

Table 2: Significant differences in NASA TLX subscales (Wilcoxon signed rank & Bonferroni adjusted alpha). Effect size is given in parentheses and is in the range medium to large

Calm Interaction, Atmosphere and Context Cues

As possible use cases for the thermal feedback, four participants (#2, #5, #16, #21) suggested calm interaction, "*...in some slow paced, passive or atmospheric use case…*" (#2), or calming effect: *"The experience itself made me calm"* (#16), and "*Cold feedback cooling hectic gameplay"* (#21). Thermal feedback was seen as a tool for creating a holistic game experience, commented by five participants (#9, #10, #12, #14, #19, #21). Also signaling emotions or emotional responses was mentioned: "*You could somehow use thermal cues with the words ´yes´ and ´no´, because temperatures have emotional charges"* (#14). Thermal feedback was also suggested to be used as a contextual cue about the game play. It could provide information of the game world either in terms of a more generic context *"In a game [thermal feedback would] represent the temperature of the environment"* (#12), or about gameplay elements: "*...in some role playing game, the effect of the fireball, or in a first person shooting [game] gun heating"* (#7). The thermal experience was also suggested for other domains, such as sensing weather forecasts (#20). Five participants (#4, #6, #7, #11, #19) commented about the possibility to use thermal feedback in situations when blind or blinded.

Intensity, Immersion and Dynamicity

When prompted on how the thermal feedback device should be designed, altogether seven participants (#2, #6, #7, #12, #14, #16, #19) suggested larger size thermal elements, e.g. *"Thermal (feedback) should be received from the entire gamepad and not just from a small area"* #6. Five participants (#5, #7, #10, #11, #19) commented about the heating speed. Because the current implementation of the thermal cues was slow, participants wanted to have faster feedback, especially in the context of the game mechanics.

The intensity and scale of the thermal feedback provoked diverse comments. Five participants (#7, #9, #10, #14, #17) commented on the power and the intensity of the thermal feedback and wished for more extreme cold and hot cues: *"You could have bigger variation in temperature"* (#9), *"...slightly more power."* (#14). However, two participants (#8, #13) perceived the feeling of the cold cues already as unpleasant: *"Cold is unpleasant for cold hands…"* (#8). Two participants (#2, #13) felt that the thermal feedback was scary, because it was new (#2) and not expected from a gamepad (#13): *"Thermal feedback was a bit scary, because normally your controller doesn't heat up, [it might] mean danger?"* (#13).

Six participants (#3, #4, #13, #15, #20, #21) felt that the heat and the sweat from their hands disturbed the thermal cues: *"Don't know if the temperature comes from my finger or the machine"* (#15), *"In the long run recognizing the heat gets more difficult, because hands get sweaty and you get used to it [heat]"* (#4), *"Normally when you're playing the gamepad gets warmer or even hot"* (#13). Participant #20 suggested an idea for dealing the sweat and taking it into account for the thermal sensation: *"Calibration according to the moisture of the skin [would be good, because] moisture cools the sensation"* (#20).

Discussion

The results of our study show that compared to the other two conditions, the thermal feedback was much slower and more inaccurate in conveying the information. There are several reasons for that. Firstly, there are hardware issues. It takes a certain time for the Peltier elements to heat-up or cool-down, while vibrotactile or visual feedback are available more or less instantly. Furthermore, as known from prior work, users can distinguish between a smaller variety of thermal cues compared to vibrotactile or visual cues [13], which may explain the drop in accuracy. Nevertheless, users were able to find the hidden circles, which this still means thermal feedback could be used as an active game element. Especially the low rating for the temporal demand of thermal feedback highlights that participants didn't feel hurried while experiencing the thermal cues. In game scenarios were the goal is not to conduct a task as fast as possible, but that are rather meant to have a relaxing or calm character, thermal feedback could be a valid design choice. Several participants mentioned that they would imagine thermal feedback to have a huge impact as an ambient game element, e.g. representing the temperature of the environment as proposed in prior work.

Conclusion & Future Work

In this paper, we explored thermal feedback as a feedback mechanism for handheld devices in a gaming context. We created a prototype game controller with vibrotactile- and thermal feedback that allowed us to compare three different types of feedback as active game elements. Our findings suggest that thermal feedback can be successfully used as an active game element, although in scenarios requiring fast response times. Furthermore, our findings highlight the possibility of using thermal feedback as an ambient feedback mechanism for games, corresponding with findings of previous work e.g. [3,7]. Exploring the latter will be the main direction of our future work.

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