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Thermal Display, based on the separated presentation of hot and cold

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Abstract

Temperature sensation is an important part of the human haptic perception. Nevertheless, thermal displays are rarely used within man-machine interfaces. One reason for this is the thermal reaction time of the transmitting contact material, which makes it hard to implement a dynamic interface. In this paper, we introduce a principle which allows a versatile presentation of heat and cold stimuli with thermal displays. The adjustable thermal changes are enabled by the separate execution of heat generation and cooling of the users skin.

1 Introduction

With respect to the display of haptic object and material properties, the temperature component is of crucial interest (Ino et al. 1993, Lederman & Klatzky 2009). There are well-founded basics for the human thermal perception and detailed models for the thermal simulation (Benali-Koudja et al. 2003, Ho & Jones 2006, Jones & Ho 2008). The thermal diffusivity of a material seems to be a distinguishing cue for material discrimination (Bergmann Tiest & Kappers 2009) as well as the heat capacity (Jones & Berris 2003). Thermal displays for material simulation have been developed by Ino (Ino et al. 1993), Ottensmeyer (Ottensmeyer & Salisbury 1997) or Caldwell (Caldwell et al. 1996) - all of them based on peltier elements as active component. Several works for the identification and discrimination of simulated material within virtual environments was done by varying scientists, like Kron (Kron & Schmidt 2003), Yamamoto (Yamamoto et al. 2004), Benali- Khoudja (Benali-Khoudja & Hafez 2004), Ho (Ho & Jones 2007), to name just a few.

Furthermore, thermal interfaces are not only suitable for material simulation within virtual environments. Through it’s emotional component this kind of perception can disclose a large potential for the ”look and feel” of common man-machine interfaces.

For example Nakashige (Nakashige et al. 2009) developed a thermal interface based on peltier elements as part of a telecommunication system and integrated the actuator in a regular trackball. A comparably system embeded in a gamecontroller is done by Baba (Baba et al. 2010). Whereas Wettach (Wettach et al. 2007) developed a thermal interface based on the heating of resistors but does not include a cooling system. Thermal interfaces based on infrared radiation are not used widespread. Some work was done by Dioniso et al. (Dionisio 1997, Dionisio et al. 1997) and Lecuyer et al. (Lecuyer et al. 2003). Both research group used the infrared radiation for controlling ambient temperature within virtual reality-systems. The introduced principle of this paper is based on infrared radiation to heat the users skin while simultaneously the same area is cooled through the surface of the device. Through weighting these individual actuators, a specific sensation can be triggered.

2 Temperature Perception

The human thermal sensory system, embedded within the skin is regarded to be one of the skin senses, alongside tactility. Precedent findings showed, that thermal perception is an important quality of material exploration (Caldwell & Gosney 1993, Ho & Jones 2007, Ino et al. 1993). Besides the conscious thermal perception of object temperature and surrounding, one of it’s functions is the observation of the bodies temperature (Birbaumer & Schmidt 2006). The receptor density is distributed unequally (Caldwell et al. 1996) with an accumulation at the bodies orifices, especially the lips (Stevens 1991). The skin temperature is perceived by warm and cold receptors in differing concentration ratios, up to 1(warm) : 30 (cold) (Jones & Berris 2002). The receptors are placed in different skin depth. Cold receptors can be found inside the epidermal skin layer at a depths of about 0.15 mm below the skin surface. The heat receptors are embedded in the dermal layer at a depth of about 0.3 mm. Therefore and for the reason of differing fiber characteristics, the latency for warm sensation is significantly above that of cold sensation (Darian-Smith 1984, Caldwell et al. 1996). Cold sensing perception cells respond within the temperature range between 5°C and 43°C with the peak at 30°C, whereas warmth receptors are within the range between 13°C and 45°C peaking at 43°C (Darian-Smith et al. 1973).

However, the individual warm and cold receptors do not give a precise reading of the skin temperature (Kandel et al. 2000) which could be caused through a unavailable fixed reference point for temperature (Bergmann Tiest & Kappers 2009). Therefore it’s difficult for humans to evaluate the absolute temperature of the skin. Both receptor cells are more sensitive to thermal changes than to static temperatures (Hensel 1973) within the perceivable range. Temperature differences of between 0.5°C and 5.2°C could be detected if applied simultaneously on a test subjects hands (Abbott 1913). The perception of a thermal change at the same spot is even better and varies between 0.1°C and 0.3°C at a rate of 0.1°C/sec or faster (Kenshalo et al. 1968). The temperature sensation is based on the perceived heat extraction rate (Bergmann Tiest & Kappers 2009, Darian-Smith et al. 1973) and there are indications for a high resolution, even for small changes in skin temperature (Johnson et al. 1979). Therefore, for temperature perception the speed and strength of temperature modification is of crucial interest. The minimum values for an observable thermal change can be found in Weber’s three tray experiment (Birbaumer & Schmidt 2006).

By decreasing the area of contact or the altering speed, the threshold values for the sensation are increasing and vice versa. Slow changes in skin temperature could hardly or not be perceived until they are rising above 36°C or falling below 30°C . Therefor it's proposed by Jones and Berris to present thermal changes in rapidly occurring transients (Jones & Berris 2002). The thermal perception is based on the basic temperature of the skin, which is generally within the range of 30°C – 35°C in an indoor environment (Jones & Berris 2002). Ordinarily, the temperature of the skin measured on the hand varies between 25°C– 36°C (Verrillo et al. 1998). If the skin temperature falls below 15°C- 18°C or rises above 45°C pain is perceived (Spray 1986, Darian-Smith & Johnson 1977).

The spatial resolution of the temperature sensory system is very limited, compared to the resolution of the mechanoreceptors (Darian-Smith & Johnson 1977, Yang et al. 2009). This resolution although varies through the human body depending on the receptor density (Darian-Smith 1984). There is an even stronger limitation in spatial resolution in the palm or the fingers of the hand (Johnson et al. 1973) compared to the human cavities like nose, eyes or mouth. However, the human hand is of crucial importance for the human-machine interaction and the capability for the use of thermal interfaces is proven often in previous works.

Besides the perceptive conditions, physical interrelations are relevant for the thermal exploration of objects. There are three possibilities of thermal transfer: Heat conduction, thermal convection and thermal radiation, and basically four properties which affects the speed of thermal convey: The temperature difference, size and flux of the contact area, the thermal conductivity and the heat capacity. For thermodynamics and therefore for thermal man-machine interfaces all of these properties are of interest. Nonetheless, most measurements of thermal displays are focused on the device itself and neglect the thermal convey to the users skin.

It is important to point out that the perceived temperature always deals with the temperature of the skin, which is not necessarily the temperature of the contact material (Jones & Ho 2008). Therfore, the speed of thermal changes within the simulator is not as relevant as the speed of thermal changes within the users skin. Which includes the heat flux between display and user.

3 Temperature Feedback

A limitation of existing thermal interfaces is the heat capacity of the thermal actuator. This "thermal storage" within the materials of the device, slows down the agility of the display. Thus, we tried to minimize the influence of the surface material and to that the influence of the materials heat capacity. Through a separated handling of heat generation within the user skin and heat deflection sudden temperature change could be achieved. The introduced prototype has a constant heat flux conducted from the user skin and generates heat on demand via infrared heating. Thus, we were able to differentiate the transmission of heat and cold by initiating the thermodynamics within the skin and not within the contact material of the interface.

It is much more difficult to generate and modulate thermal conduction than producing and controling heat, especially if the thermal transfer has to be without contact and should have no effect on the tactile perception, as it would with a cooling airstream (Dionisio et al. 1997). Due to this fact, we decided to keep the level of heat removal constant by using a peltier cooled aluminum housing as a heat sink for the skin. To implement the sensation of heat, we complimented the display area with an embedded glass lens. The heat is generated via the use of infrared rays which radiate through the transparent part of the contact area. The infrared heat is applied directly on the user and the infrared rays warm the skin rather than the surface material. The temperature change within the skin is the dominant perception. The radiation may not be identified as an autonomous heat source, so the resulting temperature summation is ascribed to the display surface.

If the heat source is turned off, the skin cools down immediately and the user will only perceive the cold temperature of the contact area. This perception leaves the impression that the thermal display cooled down. By varying the duration of the infrared illumination, the perceived temperature can be influenced (fig. 1). An interruption of the infrared radiation leads to an immediate drop within the thermal perception, because the heat sink is still at the intended low temperature.

Figure 1: Schematic depiction of the thermal currents in the adjusting knob (thermal display). Variable heat generation (red arrow) and constant heat removal (blue arrows)

4 Implementation

To generate the infrared rays, we used a Philips 100W infrared incandescent lamp with an optimized short wave length at about 1400 nm and a infrared radiation peak corresponding to the absorption factor of the human skin. These wavelengths are absorbed less by the epidermal melanin, and could penetrate deeper into the human skin (Dai et al. 2004). This supports a strong and fast heat perception and a pleasing character of the infrared heat.

The touch area of the device is a rotatory knob, build of aluminum and an embedded crystal glass lense. To keep those parts on a constant low level, a peltier element is attached. The different materials could be identified through their thermal conductivity when touched separately, but not when grasped as a whole unit. The impression of consistency is further confirmed through the seamless transition between both materials. The aluminum housing allows a fast thermal transfer and therefore a fast cooling of the skin, even if glass is not the first class material through its limited thermal conductivity.

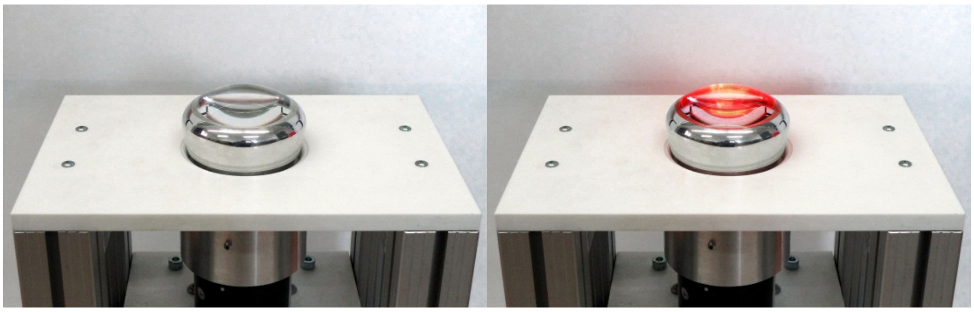

Figure 2: The thermal display integrated into the adjusting knob of a dynamic rotatory device. The embedded lense is visible in the middle of the adjusting knob. During disabled infrared radiation the aluminium housing of the device is constantly cooling the user skin through its high heat conductivity, which leads to the perception of cold. If the infrared heat source if turned on, the infrared radiation is warming the users skin. In this case, the generated heat is higher than the constant heat removal which leads to the sensation of warmth.

When designing the thermal display, we made the contact area as large as possible, so this area can constantly withdraw heat from the users palm. We decided to integrate the thermal display into a rotatory device with a large adjusting knob since this permits the maximum contact area between the users palm and the device (fig. 2). The large contact area enhances the heat conduction. The device is controlled by and comunicates through an atmel atmega 328 attached on an arduino development board. To allow a consistant cooling of the users skin a pt100 temperature probe is attached to the knob and regulates the peltier element.

5 Conclusion

The introduced functional principle with separated heating and cooling, allows the implementation of a simple, fast and low-cost thermal interface. The technology could be used on flat as well as on curved surfaces which offers a great variety of possible applications. First preliminary user tests with eight subjects have shown a strong reaction towards the implemented temperature changes. The participants touched the device constantly. They were blindfolded and used headphones with brown noise. The room temperature was kept constantly at 21°C and the subjects could acclimate for at least 15 min before the test was started. They were assigned to report every perceived thermal change as fast as possible by pressing a button. The setting consisted of 20 thermal changes within two minutes. All changes were realized in an arrhythmic sequence. Every toggle of the infrared incandescent lamp could be perceived within 0.9 seconds, in heating and cooling mode. Participant reported that the thermal changes were very compelling and most of them assigned the perceived temperatures to the touched material. For accurate adjustments of the thermal changes and to measure the users skin temperature future versions of the thermal display will incorporate a fast and contactless thermometer.

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