Design of a Wearable Research Tool for Warm Mediated Social Touches

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***Abstract*—Social touches are essential in interpersonal communication, for instance to show affect. Despite this importance, mediated interpersonal communication oftentimes lacks the possibility to touch. A human touch is a complex composition of several physical qualities and parameters, but different haptic technologies allow us to isolate such parameters and to investigate their opportunities and limitations for affective communication devices. In our research, we focus on the role that temperature may play in affective mediated communication. In the current paper, we describe the design of a wearable 'research tool' that will facilitate systematic research on the possibilities of temperature in affective communication. We present use cases, and define a list of requirements accordingly. Based on a requirement fulfillment analysis, we conclude that our research tool can be of value for research on new forms of affective mediated communication.**

***Keywords*—Mediated Social Touch; Temperature; Wearable Design; Research Tool; Affective Communication.**

I. Introduction

Social touches such as a comforting hug play a significant role in establishing and maintaining interpersonal relations, increasing pro-social behavior, and communication of affect throughout our daily lives. Moreover, interpersonal touch is essential for our emotional and physical well-being [1]. While touch can be used as additional communication channel to emphasize other emotional displays such as voice and facial expression, it is also capable of the communication of different emotions by itself [2]. In fact, touch is our primary non-verbal communication channel for the conveyance of intimate emotions [3]. Modern society and living circumstances do not always allow people to be co-located with their beloved ones. As a result, there is an identified need for computer mediated communication devices that facilitate the conveyance of affect. However, despite the fact that interpersonal social touch is of major importance in (intimate) non-verbal communication, common communication media usually rely on the auditory and/or the visual channel. Along with advancements in tactile and kinesthetic technologies (e.g., [4]), several attempts to simulate and mediate social touches have been made over the last decade [5]. The majority of the work on mediated social touch consists of the development of conceptual prototypes that aim at simulating a specific touching action such as hugging [6] or hand holding [7]. The claims with regard to the potential effects of these prototypes are oftentimes based on anecdotal evidence, rather than on systematic empirical investigations. However, preliminary research on mediated touch suggests that haptic technologies - even when the touch representation is highly degraded - indeed can induce social effects comparable with real-life touch; for instance the conveyance of emotions and affect (e.g., [8]), or increasing pro-social behavior [9].

Human social touch is comprised of a variety of physical qualities and parameters, that in combination provide meaning and/or induce certain social effects [5], [10]. However, it is difficult - if not impossible - to fully recreate a human touch by means of haptic technology. Moreover, as said, even highly degraded representations of a human touch can already induce social effects similar to real life touches. For these reasons, we think that separate investigation of the opportunities and limitations of the different physical parameters of a human touch can advance the field of mediated social touch and can facilitate the development of effective affective communication devices. For the current project, we decided to focus on one specific quality of touch: temperature. We aim at developing a wearable device that can serve as a thermal display and can simulate the warmth of a social touch. This device should facilitate systematic empirical research on how temperature can be applied in affective computer mediated communication, and is therefore referred to as 'research tool'. The idea that temperature can play a significant role in affective mediated communication is based on three premises, which we will investigate utilizing the research tool:

- Temperature is an important physical parameter of a human touch [10],
- Perceiving physical warmth can activate perceptions of metaphorical interpersonal warmth (e.g., [11]),
- One's skin temperature can function as a display of one's social and emotional state (e.g., [12]).

In this paper, we briefly elaborate on these premises and discuss related work on temperature in mediated communication, on which we base several use cases for the research tool. Subsequently, we describe the design process, as well as the evaluation of the prototype by means of a requirement fulfillment analysis.

II. Related Work

Recent research suggests a fundamental link in the insular cortex of the brain between perceptions of physical warmth and social cognition and behavior [13]. Exposure to warmth, as compared to coldness, leads to increases in altruism (e.g.,

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[14]), trust, and associations with personality traits related to the warm-cold dimension [11]. In other words: We perceive others as a socially warmer person, when perceiving physical warmth. Moreover, people tend to focus more on relationships and feel socially closer towards others after being primed with physical warmth (e.g., [15]). The link between perceptions of physical warmth and the social cognitions is bi-directional, meaning that social cognitions also can alter perceptions of the ambient temperature (e.g., [16]). Moreover, feelings of for instance social exclusion do not only lead to perceptions of a lower ambient temperature, but one's fingertips also become colder [17]. In other words: One's skin temperature may serve as a display of his or her social feelings. Related research also suggests that skin temperature can serve as a display of one's emotional state: When one experiences positive valence emotions, the skin temperature tends to increase, whereas it decreases when in a negative emotional state such as stress, pain, or fear (e.g., [12], [18]). These findings are very interesting with regard to mediated affective communication and in particular to mediated social touch. First of all because temperature may induce social effects such as pro-social behavior and possibly increased feelings of being together while physically separated. Secondly, the communication of one's emotional state by means of mediated body temperature seems an interesting interaction paradigm; in particular when considering the increased interest in the use of physiological signals for affective computing (e.g., [19]).

On the premise that temperature is an important physical parameter of a human touch, several mediated touch prototypes have been developed that incorporate thermal stimuli. Examples include an anthropomorphic cushion that can convey hugs by means of vibro-tactile and thermal stimuli: *"The Hug"* [20]. Moreover, a simulation of holding (warm) hands is provided by *"YourGloves"*, *"HotHands"*, and *"HotMits"* [21], whereas the *"Huggy Pajama"* facilitates a warm hug over a distance [6]. However, it is unclear whether the simulated touches can induce social responses similar to those of real life touches, and whether the warmth has an effect in terms of activating social cognitions related to interpersonal social warmth. However, a *"Thermal Hug"* seems to increase feelings of social presence when in a mediated collaborative task [22], and an *"Affective Tele-touch"* [23] supported physiological recovery after stress with same rates as human touch. It is however unclear whether these effects are caused by the mere (warm) physical stimuli, or by higher order processes such as the perceived intentionality.

Not directly related to social touch, but also relevant are the findings that thermal stimuli in conjunction with other media, affect the perceived affective qualities of those media: Music is for instance experienced as more positive [24] when primed with warmth. Moreover, thermal stimuli that differ in absolute temperatures and presentation style, can in themselves also induce affective responses in its receiver: Warmer stimuli seem to be perceived as arousing, whereas the hedonic qualities are mainly determined by presentation style. Pre-adjusted stimuli are perceived as being more pleasant [25].

The above-mentioned work provides interesting starting points for research on the opportunities of warmth (and coldness) in affective mediated communication, but also demonstrates that there still is a lot to be explored in order to fully understand the practical implications of this research for affective mediated communication. With the development of a wearable research tool, we will be able to advance the research on the role of warmth in mediated touch, the physical-social warmth link, and the communication of thermal signals.

III. Use Case Scenarios

The following usage scenarios describe how the research tool may be applied in a controlled lab setting, with researchers nearby. The scenarios are based on the premises and literature as discussed before, and all describe potential research aimed at investigating the impact of different temperature parameters.

A. Relative Temperature

For one type of experiments, the researcher is interested in the impact of relative changes in temperature during an experimental task. Such relative changes could be expressed as 'a temperature increase of two degrees Celsius'. When the participant attires the device, the skin temperature is measured. The researcher sees the value in a graphical user interface (GUI) on a nearby computer and decides to use this skin temperature as baseline for the experimental task. Before the participant carries out the experimental task, the device adjusts its temperature to match the participants skin temperature. The researcher can then control further changes in the temperature of the device via the GUI by setting the desired temperature and rate of change; i.e., controlling the relative changes. Finally, the researcher analyses how the relative changes in temperature affected the participant's performance on the experimental task.

The abstractly described *'experimental task'* will in the majority of the cases involve an interpersonal component, in order to investigate whether, how, and when temperature changes affect interpersonal perceptions and social behavior. One could think of mediated communication paradigms such as a collaborative task [22], stress reduction [23], or pro-social behavior [9].

B. Temperature Patterns

In another scenario, the researcher wants to test a specific pattern of temperature changes. For this purpose, he or she programs the intended pattern using the GUI. An initial temperature is set and parameters for the desired temperature as well as time-span and rate of change are defined. When the device is started, it warms to the programmed starting temperature. Once this temperature has been reached, a participant can attire the device, which then thermally displays the pre-programmed pattern. The participant's perceptions of the temperature pattern are recorded. The aim of this type of experiment is mainly to gain insights in how people interpret thermal signals, on the premise that it is a representation of someone else's skin temperature; to what extent can and do people consequently interpret the affective and social meaning of thermal pattern?

C. Mediated Touch

In a third scenario, the research tool is augmented with other haptic actuators such as vibro-tactile stimuli in order to better approach the complex composition of a human touch.

The research tool is pre-programmed to remain at a specific temperature throughout an experimental task, while the other actuators provide stimuli. The researchers are interested in how participants perceive the different types of touches, how these touches affect certain social perceptions and behavior, and what the added value of the temperature is in this simulated touch composition.

IV. Requirements Analysis

Requirements for an adequate prototype of a wearable device for research on the role of temperature in mediated social touch have been derived from literature as well as a needs analysis based on several research plans. The derived requirements are categorized according to the three key factors functionality, wearability, and communication. Within these categories, requirements are prioritized according to the MoSCoW method [26].

A. Functionality

1) F.1: Priming with Warmth: First and of the highest priority, the resulting research tool must be able to prime subjects with warmth. In particular, it must be capable of outputting a temperature range of 26 to 38 degrees Celsius. This range has been used in prior work and established as design recommendation as referred to by Halvey (2013) [27]. This range includes the range of typical skin temperatures and also provides options for thermal stimuli outside of the thermal neutral zone (i.e., in which thermal changes are difficult to perceive).

2) F.2: Temperature Manipulations: The device must further allow for subtle manipulations in temperature output [14]. It should allow for a change of stimulus rate of one degree Celsius per second, ideally it could allow for a change of three degree Celsius per second, as this higher rate might be more attention grabbing [27].

3) F.3: Temperature Measurements: In order to verify research results, the device must be capable of measuring temperature. It must be able to measure the wearer's skin temperature to allow reporting relative changes as described in the first usage scenario. A measurement accuracy of +/- 0.5 degree Celsius should be high enough to make distinct statements. Additionally, the device should measure its own output temperature as it is received by the wearer, thus above the fabric layer. This is intended to detect temperature discrepancies caused by the fabric and allow for adjustments to avert these.

4) F.4: Graphical User Interface: In addition to the aforementioned functionalities, the device must be adjustable in near real-time by researchers during experiments. For this purpose, a graphical user interface must be developed to assist researchers preparing and executing experiments. This GUI must be able to control the temperature output of the device. It should allow to save the changes in a log-file. Ideally, it should facilitate the programming of temperature patterns as described in the second use case scenario.

B. Wearability

1) W.1: Comfort: Wearable technology comes with specific requirements that have been outlined in prior research. To be truly considered wearable, the device must be easy to wear and take off [28]. It should further be comfortable [28] and unobtrusive [29], through being lightweight and silent [30].

2) W.2: Mobility and Fit: The device should be mobile [29], in a way that it maintains the wearers range of motion [28]. The device should be held tight on the body [30] to allow effective priming and simulate the closeness of physical touch. To avoid limiting a research participant sample it should further be suitable to fit participants of varying height and weight.

3) W.3: Safety and Hygiene: For hygiene and safety reasons the materials used must be washable [28], [29] and must not cause skin irritation [28]. The device must always be accessible to the wearer [29] and should allow the wearer to quickly and easily interrupt the temperature output in case of discomfort.

C. Communication

1) C.1: Serial Communication: The device must be able to transmit the recorded temperature to a computer located in the same room to allow the researcher to observe changes in temperature in near real time. The temperature must further be controllable by the researcher from the same computer. The connection could be made via a long cable. Ideally, the device would communicate wirelessly, but considering the fact that the majority of the envisioned studies will take place in a lab setting, wired communication is not deemed a severe problem.

V. Design

On the base of the aforementioned requirements, a prototype has been designed to illustrate the feasibility of a research tool. Design choices are explained below.

A. Interaction: Arm around Shoulder

To determine the form the wearable device should take, user interaction was the first factor to be established. The device is intended to simulate social touch, therefore it must convey a meaningful social experience. Prior work has often concentrated on hugs as meaningful gesture, as demonstrated by DiSalvo's 'The Hug' [20], Gemperle's wearable tactile display [30], or Teh's 'Huggy Pajamas' [6]. Current research mainly focuses on family hugs, a long and firm embrace that often happens between parents or grandparents and children. This type of hug is a display of family affection and can be for comfort, greeting, or on departure [31]. Taking a look at another intimate gesture may enable new insights in mediated touch experiences. Therefore, this project focuses instead on the so-called 'shoulder drape'. In this type of touch, one's arm casually lays over the shoulder of the person next to him or her. That person may have his or her arm around hugger's back or waist (especially if the other person is shorter). This type of touch, which is categorized as *'Not so much a hug as an expression of closeness (and possibly jealous possession)'* [31], typically has a long duration. A wearable device that simulates a shoulder drape must intuitively cover parts of the wearer's shoulders and upper back. Possible types of clothing that typically enable such a coverage include scarfs, pullovers or t-shirts, and jackets or vests.

B. User Experience

The tool should be easy and comfortable to use, for both researchers and a participants. This includes quick and easy attire and take off, as well as a straightforward setup and usage procedure. Based the requirements for wearability, a vest has been chosen as the most appropriate type of wearable. The reasoning behind this choice is manifold, e.g., a vest can be worn by participants of varying height and weight, as it allows for easy adjustments to the wearers body type. The fact that it can be quickly taken on and off has led to usage of the shape in a variety of contexts that require fast attire, such as emergency and warning vests, bullet-proof vests, or tactical vests. Prior work on mediated touch has also utilized vests or harnesses, stating that all participants were able to try them on (e.g., [6], [30]). Authors also noted the benefit that a vest can be worn on top of participants everyday clothing, thus no preparations for changing are necessary.

C. Vest Design

1) Sketches: A series of sketches were used to communicate vest design ideas between researchers. All designs aimed to combine practical issues, i.e., how technology could be integrated, with aesthetic concerns. A selection of these sketches can be found in Figure 1. Key elements that repeatedly came up were the ability to adjust the waist area to support requirement W.2, a high collar that allows for direct skin contact inspired by requirement F.3 as well as buttons or zippers that act as emergency switches with respect to requirement W.3.

2) Materials: The sketches provided guidelines for the design of sewing patterns for a first fabric prototype. In the areas to be primed with warmth, this prototype consists of fireproof fabric. The collar area, which should be perceived as comforting, is made from a woolen fabric. Figure 2a shows the resulting vest.

3) Hardware: Warmth can be produced by a variety of electronic components. However, most do not fit the requirements concerning the desired accuracy and rate of change. Peltier elements, also known as thermoelectric elements (TE), provide these by making using of the Peltier effect. A TE module is composed of N and P-type semiconductor legs (thermoelectric couples) that are electrically connected in series, thermally in parallel and placed between two ceramic plates. These ceramic plates form the hot and cold side of a Peltier element.

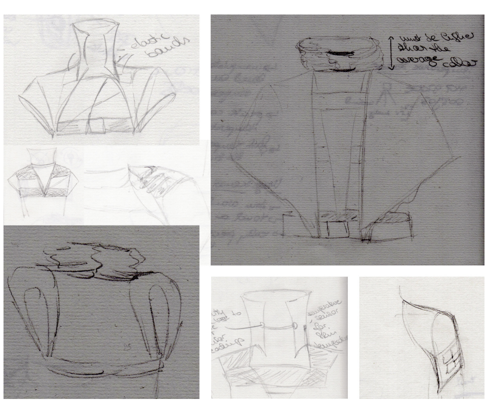


Fig. 1: Sketches of the vest.

An Arduino microcontroller controls the temperature and rate of change using N-channel MOSFET. A MOSFET allows control over high-power devices with very low-power control mechanisms. In this case they are necessary to allow the Arduino to control the voltage source of Peltier elements that operate at 8,5 Volts. As the MOSFETs themselves can reach very high temperatures, they have to be attached outside of the vest to avoid uncomfortable heat sensations for the wearer.

Two temperature sensors are used to keep track of the wearers skin temperature as well as the temperature that the wearer is primed with. For this purpose, one of them is attached to the inside of the vest's collar. It makes direct contact with the wearer's skin, measures the temperature, and converts it into voltage that can then be interpreted by the Arduino. A second sensor is attached on the inside of the vest, opposite to a Peltier element. It measures the temperature that the participant is primed with. A complete overview of the developed circuit can be seen in figure 2b.

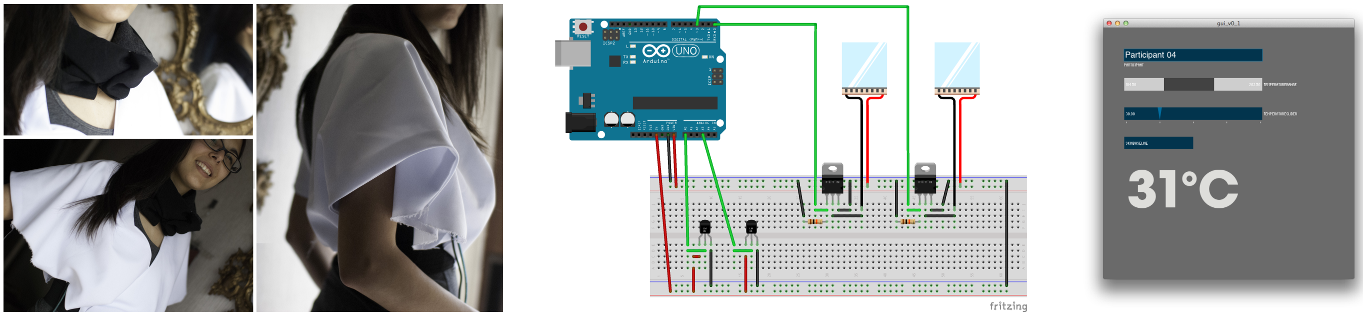
4) Software (GUI): Researchers should be able to communicate with the vest from a nearby computer. A graphical user interface (GUI) was written in the Processing programming language and connected to the microcontroller using Serial protocol. The GUI in its current form is suitable for the first usage scenario, thus allowing the researcher to manipulate the output temperature in near real time. Functionality that allows the second usage scenario, programming a series of interactions beforehand, was only implemented at a basal level. Future iterations should expand this functionality. In figure 2c, the GUI and its elements are described.

VI. Results

Given the broad variety of individual requirement aspects for functionality, wearability, and communication to be confirmed, no single evaluation method could be used to reliably test all of them. Thus, a series of different evaluations has been performed, some of them technical and some with small amounts of users. Table I reports the methods of these evaluations and the prototype's performance. Four key requirements determine the functionality of the prototype. All 'musts' of those have been fulfilled in the current iteration, thus all core functionalities have been implemented. However, the temperature measurements should be more accurate than they currently are, see requirement F.3.2. The wearability requirements have largely been fulfilled, the device has shown to be comfortable to wear, safe, and hygienic. The prototype does however limit the wearer's range of motion due to its dependency on cables for power supply and serial communication. The requirement that the device must be able to communicate with a nearby computer, in a way that it can both send and receive data has been fulfilled, as the device can be controlled via serial communication.

VII. Conclusion and Future Work

The requirements analysis showed that the current version of the prototype generally performed well, but does not yet fulfill all requirements. In total, twenty-one of twenty-four requirements have been fulfilled, which can be seen as a



(a) (b) (c)

Fig. 2: Components of the wearable research tool prototype. A: Prototype vest design, B: Prototype circuit, C: GUI and interface elements.

satisfying result for the first step in development. In the following paragraphs conclusions from the aspects that have not yet been fulfilled are drawn, leading to suggestions for future work.

While the prototype performs sufficiently in terms of the envisioned functionality, it does suffer from the lack of accuracy of the temperature sensors that were available within the scope of this project. To make it a fully reliable research tool, the temperature should be reported as accurately as possible. This could be solved by using a more accurate sensor, which might have the added benefit of sensing the temperature faster as well, allowing the researcher to respond faster to changes in temperature. Such a change is of high priority for future iterations. Another limitation of the prototype is its dependency on cables for power supply and communication, which prevents it from allowing the wearer unrestricted mobility. The power supply could be substituted by a battery pack, however this may not be a sustainable solution as particularly the Peltier elements require a lot of power. The durability of battery packs and therefore the risk of running out of battery during an experimental session should be investigated. Further, weight and size of the batteries should not interfere with other wearability requirements. To replace the USB cord for serial communication, several technologies and/or protocols might be appropriate, such as Radio Frequency (RF), WiFi, or Bluetooth. An investigation of each of these technologies will determine the feasibility of wireless communication for further prototype iterations. By implementing both, wireless power supply and communication, the device could be truly considered wearable.

TABLE I: METHODOLOGY AND RESULTS OF THE REQUIREMENT FULFILLMENT ANALYSIS.

Requirement	MoSCoW	Description	Fulfilment Criteria	Fulfilment
F.1	M	prime subjects with temperature range of 26C to 38C	datasheet, confirmed using temperature sensor	YES
F.2	M	allow manipulations of temperature output	functional serial communication implemented	YES
F.2.1	S	change of stimulus rate of 1C / second	datasheet, measured using temperature sensor	YES
F.2.2	C	change of stimulus rate of 3C / second	datasheet, measured using temperature sensor	YES
F.3	M	capable of measuring temperature	circuit contains working temperature sensor	YES
F.3.1	M	measure the wearers skin temperature	sensor placed at wearers skin	YES
F.3.2	S	measurement accuracy of +/- 0.5C	datasheet	NO
F.3.3	S	measure priming temperature	sensor placed at priming area	YES
F.4	M	adjustable in near real-time via GUI	functional serial communication implemented	YES
F.4.1	M	able to control temperature output	serial control implemented	YES
F.4.2	S	save the changes in a file	writing events to CSV file implemented	YES
W.1	M	comfortable to wear		YES
W.1.1	M	easy to wear and take off	can be attired and taken off in less than 30 seconds each	YES
W.1.2	S	unobtrusive	W.1.2.1 and W.1.2.2 fulfilled	YES
W.1.2.1	S	lightweight	less than 1 kg, measured on a weighing scale	YES
W.1.2.2	S	silent	less than 30 dB measured with Sound Meter App	YES
W.2	S	mobile and well-fitting	W.2.1 and W.2.2 fulfilled	NO
W.2.1	S	maintain wearers range of movement	real-world test in a typical lab	NO
W.2.2	S	fit participants of varying height and weight	test with extreme participants: female 1,60m (45kg), male 1,96m (100kg)	YES
W.3	M	safe and hygienic	W.3.1 - W.3.3 fulfilled	YES
W.3.1	M	washable	functional test after machine wash at 40C	YES
W.3.2	M	no skin irritation	visual observation before and after wearing for 30 minutes	YES
W.3.3	S	quickly and easily interrupt the temperature output	power cable accessible to be pulled out	YES
C.1	M	communicate with a computer	C1.1 and C.1.2 fulfilled	YES
C.1.1	M	transmit recorded temperature to a computer	display of measured temperature on GUI	YES
C.1.2	M	determine output temperature from a computer	device reacts to GUI input	YES

Implementation of the temperature pattern use case scenario is another point for future work. A functionality that allows programming specific timed events would increase consistency between experiments, as each participant could be primed with the exact same pattern, which would allow explicit investigation of interpretation differences between thermal patterns. At the same time, it could enable the researcher to leave the room, which may be beneficial for certain experimental designs as well. By attaching hook and loop fastener to the inside of the vest, the device could be combined with other haptic actuators and thus serve the mediated touch use case scenario.

Finally, one must consider the limitations of a requirement fulfillment analysis as evaluation method for such a device. Real-world usage of the prototype may reveal unforeseen issues that, despite the effort to be thorough, have not been considered in the requirements. A future iteration of the prototype will have to prove its application for research in a realistic setting. We envision an evaluation paradigm in which all use case scenarios will be addressed.

In summary, we have argued why having a wearable research tool that can display several thermal patterns is valuable for our research, and for the research on affective mediated communication in general. We have presented a first prototype, and conclude that this specific design forms an appropriate basis for future iterations that will eventually lead to a fully functional prototype that is suitable for our envisioned research. With clear goals for future iterations in mind, the actual usage of such a research tool in experimental settings can and will become visible in the near future.

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