

The TaSST - Tactile Sleeve for Social Touch

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ABSTRACT

In this paper we outline the design process of TaSST (Tactile Sleeve for Social Touch), a touch-sensitive vibrotactile arm sleeve. The TaSST was designed to enable two people to communicate different types of touches over a distance. The touch-sensitive surface of the sleeve consists of a grid of 4x3 compartments filled with conductive wool. Each compartment controls the vibration intensity of a vibration motor, located in a grid of 4x3 motors beneath the touch sensitive layer. An initial evaluation of the TaSST was conducted in order to assess its capabilities for communicating different types of touch.

Index Terms: K.6.1 [Management of Computing and Information Systems]: Project and People Management—Life Cycle; K.7.m [The Computing Profession]: Miscellaneous—Ethics

1 INTRODUCTION

In our daily interaction with the world around us we not only use our tactile sense for sensory discrimination (e.g. exploring shapes and textures), but also to engage with others around us [10, 24]. These social touches range from accidentally bumping into a stranger in a busy store, and deliberate handshakes as a means of introduction, to intimate hugs given to loved ones. In human-computer interaction and computer-mediated communication our sense of touch is used in a similar fashion. Haptic feedback allows us, for example, to feel and manipulate virtual objects [31]. Recently researchers have started to explore ways in which haptic feedback can be used to communicate through touch over a distance. Prototypes of these mediated social touch [14] devices include devices to feel someone's presence over a distance [4], devices that augment existing communication channels [5], and devices for intimate contact over a distance [25]. However, most of the current devices only have limited degrees of freedom, restricting interaction to a single touch. In this paper we argue that different types of touch are important in different social situations. To this end, we present the design process of a device that enables two people to engage in synchronous mediated social touch through a forearm-mounted conductive wool sensor grid, and vibration motor actuator grid. We investigate the capabilities of the device to communicate different types of touch.

2 RELATED WORK

2.1 Social touch

Morrison et al. [24] define three main categories of nonsexual, positively hedonic forms of social touch, namely: simple, protracted, and dynamic. First, “simple” touches involve touches that are brief, intentional and relatively restricted to certain body

locations such as the arm or hand. An example of simple touch is tapping someone on the shoulder to get his/her attention. Second, “protracted” touch involves longer and often mutual skin-to-skin contact where a form of pressure is applied, such as when giving someone a hug. Third, “dynamic” touch involves continuous, often repetitive movement over the skin, as for example in stroking. When these types of touches are applied to the hand, arm, or shoulder in social settings, they can have a number of effects on affiliative behavior and the maintenance of social bonds [24]. Touch can increase the liking of the toucher, and increase the likelihood of compliance to requests [10, 19]. For instance, when a waitress briefly touches the forearm of a customer (simple touch), the customer is more likely to give a tip [12]. Furthermore, touch can have stress reducing effects [9], for example, holding a loved one's hand (protracted touch) can reduce anxiety caused by an impending threat [7]. Similarly, stroking (dynamic touch), as compared to other forms of touch, can induce positive affect in infants [28]. Apart from these direct affective consequences, touch can be used to communicate discrete emotions [17, 19]. Studies have shown that people can communicate specific emotions to one another by using simple, protracted, and dynamic touches on the forearm of another person [18]. Participants employed emotion specific touch behaviors to distinguish between different emotions. For instance, simple touches, such as hitting, are associated with anger, whereas dynamic touches, such as stroking, are associated with love [18].

2.2 Mediated social touch

The concept of mediated social touch refers to people touching each other over a distance by means of haptic feedback technology [14]. In mediated touch, input devices are used by the toucher to engage actuators that stimulate the tactile sense of the receiver of the touch. For example, [30] present four actuator designs that aim to mimic human touches, such as tapping (simple), squeezing (protracted), twisting (protracted), and dragging (dynamic). Though these actuators offer promising possibilities for touch over a distance, an issue is that they are relatively large, and thus not suitable to cover a larger surface and still be worn comfortably on the body. More common in prototypes designed for mediated social touch, is the use of vibration motors to simulate a touch. As stated in the introduction, most of these devices have limited degrees of freedom, and are thus more geared towards delivering a single, specific tactile sensation, or more symbolic tactile messages, such as vibrotactile patterns representing certain emotional states. [2, 8, 11, 16]. There are some noticeable exceptions however. ComTouch [5], a hand-held device that was envisioned to augment communication through a mobile phone, uses force-sensitive resistors to control the intensity of vibration of vibration motors placed under a single finger. This way, tactile signals can be communicated between two users. Similarly, CheekTouch [27] consists of a 3x3 grid of vibration motors placed on the back of a mobile phone. Touches on the touch screen of one phone make vibration motors on a second phone vibrate in the same location as where the touch was applied on the touch screen of the first phone. CheekTouch aims to aid with non-verbal and emotional communication during a telephone conversation. Both these examples allow users to vary the touches they use by changing

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either intensity (ComTouch) or location (CheekTouch).

Apart from applications in the design of prototypes, vibrotactile stimulation has been successfully applied in studies investigating similarities between real and mediated social touch [13, 15]. It is well known from psychological studies that touch can increase the likelihood of compliance to a request [10, 19]. Similarly, when vibrotactile stimulation was used to simulate a touch to the upper arm, helping behavior increased in a way that was comparable to studies using real touch [15]. Furthermore, the appropriateness of vibrotactile stimulation applied by a stranger to different body sites of the receiver, including the back, abdomen, upper arm, and wrist, is perceived similarly to real touches applied to those body sites [13]. These findings indicate that vibrotactile stimulation is an appropriate method of actuation for mediated social touch. Moreover, the forearm seems an appropriate body-site for mediated social touch to occur [13, 18, 19].

2.3 Vibrotactile stimulation of the forearm

A number of studies have investigated tactile perception of vibratory stimuli (e.g. vibration motors) placed in a grid on the forearm [6, 26, 29]. For example, it has been found that changes in frequency and amplitude are difficult to perceive, while location and duration of, as well as the spacing between stimuli, have a more profound impact on the perception of vibrotactile stimuli [6, 21, 26]. When vibrotactile stimuli are placed in close proximity to body landmarks (e.g. wrist, elbow, edge of the arm) localization accuracy increases [6, 26]. Increasing the inter-stimuli spacing from 25mm to 50mm increases single-point identification [6]. Decreasing inter-stimuli spacing to 15mm creates a more intense sensation and is possibly more appropriate for tactile apparent movement (i.e. a sensation of a single point moving across the arm) [22, 26]. These findings provide valuable insights for the design of forearm mounted tactile displays. For example, spacing between the motors, as well as their location on the arm can be used as design parameters.

3 THE TASST

3.1 Concept

Based on the considerations outlined above, we designed the TaSST (Tactile Sleeve for Social Touch, Figure 1). The TaSST allows two people to synchronously engage in mediated social touch by touching their own forearm. When two people both wear a TaSST on their arm, a touch to the forearm of the sender is felt as a vibration on the forearm of the receiver. The forearm was chosen because it is relatively sensitive to vibrotactile stimulation [26], easily accessible to touch, and an appropriate location for social touch to occur [13, 18, 19]. The concept of the TaSST is similar to ComTouch [5] and CheekTouch [27], but includes both intensity and location as parameters, offering more degrees of freedom for touches to be communicated. Furthermore, the TaSST offers a more direct coupling between the input and output: a touch on the senders own arm will be felt on the arm of the receiver in the same location and with the same intensity.

3.2 Components of the TaSST

The system consists of two sleeves that are both composed of an input layer and an output layer controlled by an Arduino Mega micro controller. The input layer is a 4 by 3 grid of 40mm by 40mm Lycra pads, filled with conductive wool (Bekeart Bekinox w12/18). When compressed, the resistance of the wool changes, effectively making it a soft, flexible touch sensor. The advantage of this approach is that the wool-filled compartments are relatively sensitive, detecting changes in force of around 0.4 N. Moreover, the sensors are scalable, do not require a rigid surface to function, and are easily integrated into garments, making the sensor grid suitable to wear on the body.

The output layer is a 4 by 3 grid of pancake style eccentric mass vibration motors (KOTL KB37B3) attached horizontally to a felt sheet. The motors are 12mm in diameter and 3mm in height. The rotation speed of each motor is controlled by the amount of force that is applied to the wool-filled compartments, so that more force results in stronger vibrations. The vibration motors do not allow for frequency and amplitude to be manipulated independently. However, considering the fact that frequency and amplitude changes are difficult to perceive [21, 26], the vibration motors were considered to be well suited for vibrotactile stimulation. We opted for an inter-motor spacing of 40mm to allow for relatively accurate single-point identification (e.g. poking) [6, 26]. Because little is known about the exact spacing requirements for tactile apparent movement without using ‘anti-aliasing’ methods (i.e. algorithms that create a smooth transition by manipulating the vibration intensity of two motors [3]), we chose a spacing that seems to favor single-point identification over tactile apparent movement. We chose not to implement an algorithm for anti-aliasing at this point, as this would introduce a delay between input and output.

The output layer is secured around the dorsal side of the forearm using Velcro straps. The input layer attaches to these Velcro straps (Figure 1). The total size of the sleeve is 160mm by 120mm by 30mm.



Figure 1: The TaSST. The input layer is attached to the top of the output layer using Velcro.

3.3 Calibration

The wool in the compartments has the tendency to settle after being touched, producing noise in the data stream. To calibrate the sensors the wool is first fully compressed and then left in idle state to determine the lower and higher threshold. Data from the compartments is smoothed using a low-pass filter and sampled with a 10ms sampling rate. The vibration motors are controlled using PWM (pulse width modulation). Similar to [26] we defined 7 PWM levels resulting in 7 perceptually different vibration levels of the motors. For calculating the PWM values the system uses the conductivity range of the wool between fully compressed (lower threshold) and idle values (higher threshold), dividing this into seven PWM levels.

4 USER STUDY

A user study was conducted to assess the capability of the TaSST to communicate simple, protracted and dynamic touches. Our hypothesis was that certain vibrotactile patterns would be perceived as specific touches to the input layer of the TaSST. These vibrotactile patterns would differ in intensity, location, and duration of vibrations. To this end we recorded simple (poking and hitting), protracted (pressing and squeezing), and dynamic (rubbing and stroking) touches with the input layer of the TaSST (Figure 2). Each touch was applied by the experimenter, and recorded multiple

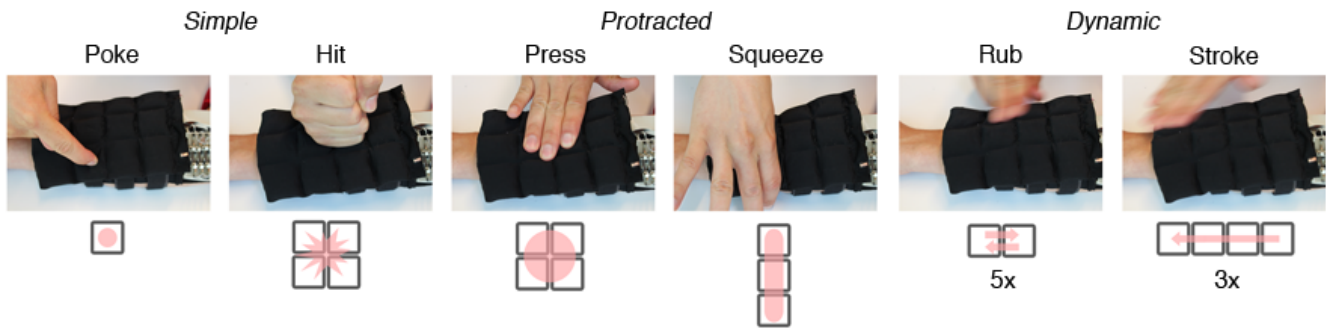


Figure 2: Prerecorded touches, selected from [18], that were presented to participants. The diagrams indicate how, and how many compartments were touched for each touch. Touches were selected and encoded so that they could be expressed using the TaSST.

times to arrive at a well recognizable version of the touch (i.e. a prototypical touch of each type). This way, four variations of each touch were recorded, with different locations and orientations (e.g. a stroke over the length or width of the input layer). These locations and orientations were chosen to be close, or further away from bodily landmarks such as the wrist, edge of the arm, and elbow, as well as be oriented along or across the arm. We chose only a small subset of all possible variants in order to have a workable set of stimuli. Because the touches were recorded by the experimenter in a controlled setting prior to the experiment, the recordings should be considered a "best case" scenario. To get an idea of how clearly each prerecorded touch would be recognized when 'played back' through the output layer, we asked participants to imitate the touch they thought they received.

4.1 Participants

The study featured 10 participants (8 male, 2 female) who were all students and staff members of the HMI group of the University of Twente. The mean age was 28.3 (SD = 2.9). The average circumference of participants' non-dominant wrist was 169.2 mm (SD = 13.1mm).

4.2 Procedures

Participants took place behind an opaque screen, signed an informed consent sheet, and were given a written explanation of the experiment, and the functioning of the TaSST. Then, the measurements of the participants wrist were taken. The output layer of the TaSST was attached to the participant's non-dominant arm, so that the middle of the output layer was aligned with the centre of the participant's wrist. The input layer was attached to the top of the output layer. Next, participants were told someone on the other side of the screen would apply a number of touches to a sleeve identical to their own. It was participants task to think about how the person on the other side touched his/her sleeve, and to try to imitate this touch by touching their own sleeve. In reality the participants received, in random order, the 24 prerecorded touches (Figure 2). After receiving each touch twice consecutively, participants imitated the touch on their own sleeve, and indicated verbally that they were ready to receive the next touch. Finally, participants indicated their age, gender, and general comfort level while wearing the sleeve. During the experimental procedure, participants wore headphones playing white noise to block out the sound produced by the vibration motors. The entire experiment was video recorded from two different angles (top-down as in Figure 2, and from the side).

4.3 Data analysis

To assess how well participants were able to imitate the prerecorded touches they received through the output layer of the TaSST, we

Table 1: Crosstabulation of the categories of prerecorded touches (stimulus) and touches coded from the videos (response).

Stimulus	Response			Total
	Simple	Protracted	Dynamic	
Simple	44	25	11	80
Protracted	22	38	20	80
Dynamic	29	24	26	79
Total	95	87	57	239

wanted to know how they touched the sleeve (type of touch), how long they touched the sleeve (duration), and how much of the sleeve they touched (surface area). The type of touch was obtained from annotated video data. The duration of the touches was recorded from the moment of first contact with the surface of the input layer, until the last moment of contact. The data was averaged for the four variants of each touch. Finally, the surface area was obtained by counting all unique sensors that a participant touched while imitating a prerecorded touch. If a participant touched a sensor twice this was counted as a single sensor activation. Again, the data was averaged for the four variants of each touch.

4.4 Results

4.4.1 Types of touches

Based on the videos, two raters, unfamiliar with the order in which the touches were applied, coded each touch made by participants. The coding scheme used was based on [18] and included the following items: rubbing, poking, stroking, massaging, pressing, squeezing, scratching, hitting, tapping, trembling, and pinching. Substantial inter-rater reliability was obtained with Kappa = .78, $p = <.001$, 95% CI (.716, .836). In a first discussion round between the raters consensus was obtained on all touches. In a second discussion round, touches were recoded into the three categories of touch (i.e. simple, protracted, and dynamic). From these data, a cross tabulation for the prerecorded (stimulus) and coded (response) touches was computed (Table 1). What can be observed from the table is that when presented with simple and protracted touches, participants mostly responded with simple and protracted touches respectively. For dynamic touches however, Table 1 shows considerably more confusion, with responses spread out over all categories. This finding could be explained by the fact that the spacing between the vibration motors (40mm) might be less well suited for generating tactile apparent movement [22], making dynamic touches feel more like consecutive pokes, or presses, instead of, for example, a stroking motion. Specific touches that were most used by participants were poking (94), pressing (58),

and stroking (39). This indicates that participants used a variety of touches from all three categories, instead of relying on a single form of touch. However, one participant remarked that because the input layer consists of separate thick compartments, he was more inclined to use simple and protracted touches. Moreover, another participant remarked that because the input layer was soft, he had the feeling that he had to apply considerable force for his touch to be registered. Therefore he used more protracted touches. Finally, participants indicated that the sleeve was comfortable to wear ($M = 3.90$, $SD = .99$, scale of 1-5 where 1 is "very uncomfortable, and 5 is "very comfortable"). Wrist size did not influence comfort levels ($F(1, 9) = 2.97$, $p = .1$).

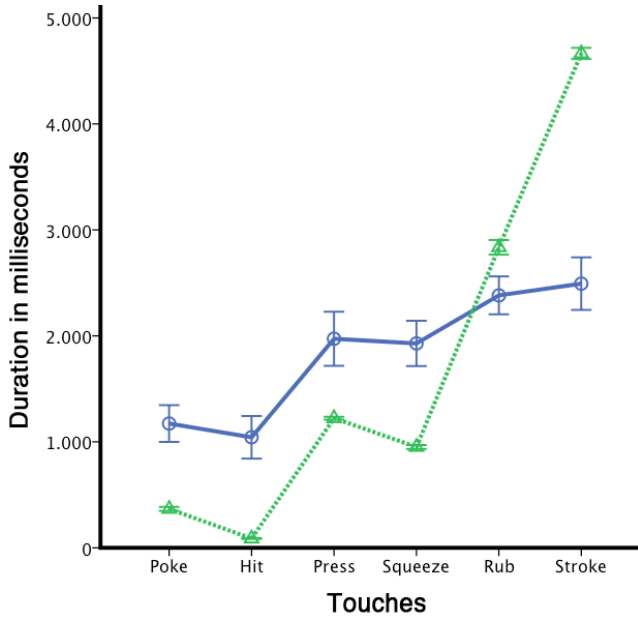


Figure 3: Average duration of pre-recorded touches (triangles) and touches by participants (circles). Bars indicate standard error.

4.4.2 Duration of touches

First, the duration of the touches made by participants was compared to the duration of the prerecorded touches, using one-sample t -tests. All touches showed a significant difference ($p < .05$), except for rub ($p < .70$). This indicates that, except for rub, the duration of the participants' touch differed from the prerecorded touches, as can be observed from Figure 3. For the relatively brief prerecorded touches poke, hit, press, and squeeze (all less than 1300 ms) participants overestimated the duration when they were asked to imitate the touch. Conversely, for stroke (about 4600 ms), participants underestimated the duration when they were asked to imitate the prerecorded touches. These results were the same when touches were collapsed into their touch categories (i.e. simple touches: poke, hit; protracted touches: press, squeeze; dynamic touches: rub, stroke), and compared to the prerecorded touch categories using one-sample t -tests (all touch categories were significantly different from the prerecorded touch categories with $p < .01$). However, Figure 3 does show that the data follow a trend that is similar to the prerecorded touches. This trend indicates that, when imitating the touches they received, participants showed a tendency to distinguish temporally between different touches in a similar fashion as the prerecorded touches were distinguished temporally (i.e. duration of simple < protracted < dynamic). Second, touches made by participants were compared to each other. Touches made by participants were compared using a repeated

measures ANOVA, but no significant differences were revealed. However, a repeated measures ANOVA with Bonferroni correction, for which the touches were collapsed into their touch categories, revealed a significant difference between the duration of simple (1108 ms) and dynamic (2423 ms) touches ($F(1,9) = 274.92$, $p < .05$). Participants successfully distinguished between these two touch categories on the temporal dimension. This partially supports the trend that can be observed in Figure 3.

Table 2: Average number of vibration motors activated (stimulus) compared to the average number of sensors activated (response) for all touch types, using a one-sample t -test.

Touch type	Average number of vibration motors activated (stimulus)	Average number of sensors activated (response)	Significance
Poke	1	2.73	$p < .005$
Hit	4	2.05	$p < .000$
Press	4	3.58	<i>n.s.</i>
Squeeze	3	3.63	<i>n.s.</i>
Rub	2	2.90	$p < .008$
Stroke	3.5 ¹	2.88	<i>n.s.</i>

4.4.3 Surface area of touches

To assess potential differences between the surface area touched by participants in response to a touch they received, a comparison (one-sample t -tests) was made between the average number of motors activated for each prerecorded touch and the average number of sensors touched by each participant. These data are shown in Table 2. A significant difference was found between prerecorded touches and touches made by participants for poke, hit, and rub. For poke, and rub participants overestimated the surface area of the touch. A potential explanation for this is that, especially in the case of rub, the surface area was relatively small, but stimulated for a longer duration. It is possible that the fabric sheet, to which the motors were attached, vibrated when motors were activated. In the case of relatively localized touches (i.e. poke and rub), these vibrations might have been perceived as activations of surrounding vibration motors. Conversely, for hit, participants underestimated the surface area of the touch they received. This might be due to the fact that hit was very brief in duration (see Figure 3). It is conceivable that the duration was too brief for participants to feel hit as activation of four motors, and instead perceived activation of a smaller surface area (2.05 motors on average). Next, touches were collapsed into their touch categories (i.e. simple touches: poke, hit; protracted touches: press, squeeze; dynamic touches: rub, stroke), and compared to the prerecorded touch categories using one-sample t -tests. No significant differences emerged between the average number of motors activated (stimulus) and the average number of sensors touched by participants (response).

4.4.4 Conclusions

The results from the user study indicate that participants had the most difficulty in imitating the type of touch when they received a dynamic touch through the output layer. When participants received a simple or protracted touch, they mostly responded with a touch from the same touch category. When the duration of prerecorded touches was compared to the touches made by participants, a

¹Note that stroke had two lengthwise variants (4 motors) and two widthwise variants (3 motors) resulting in 3.5 motors activated on average over all four variants of stroke.

similar trend for both types of data was observed. However, all touches, except rub, differed significantly from the prerecorded touches. Still, participants were able to distinguish between simple and protracted touches on the temporal dimension, lending partial support to the trend observed in the duration data. Finally, a comparison between the number of vibration motors activated and the number of sensors touched by a participant, revealed significant differences for the simple touches poke, and hit, and for the dynamic touch rub. No significant differences were found for the protracted touches press, and squeeze. Overall, no significant differences were found between the average number of vibration motors activated and the average number of sensors touched, for the three touch categories.

Overall the data indicate that the first version of the TaSST is more suitable for protracted touches, such as pressing and squeezing. Simple touches were also imitated relatively accurately, but participants overestimated the surface area of these touches. Dynamic touches were the most difficult to imitate, which indicates that the current version of the TaSST is not well suited for dynamic touches. In the next section we present a first redesign of the TaSST based on the results from this user study.

5 REDESIGN: TASSST 1.5

Based on the results a number of changes were made to both the input layer and the output layer of the TaSST. Two remarks were made by participants regarding the input layer of the TaSST. A first participant remarked that because the input layer was so soft, he had the feeling he had to press hard for his touch to be registered. A second participant remarked that because the input layer consisted of separate thick compartments, he used more simple and protracted touches. Based on these comments we decided the input layer needed to be, thinner, firmer, and smoother. To achieve this, we used a dry felting technique. A 40mm x 40mm x 10mm mold was used to shape the raw conductive wool into square pads with the same dimensions as the mold. This resulted in sensor compartments that were firmer and thinner, but still allowed for 7 distinct levels of force to be detected. The reduced thickness of the sensor compartments also made the input layer smoother overall, compared to the thicker ‘cushions’ of the original TaSST. Moreover, the firmer sensor compartments allow the input layer to be covered by an extra fabric sleeve, without interference, making the sensor compartments less distinguishable. These changes should provide users of the TaSST 1.5 with an input surface that is more suitable for dynamic touches, compared to the input surface of the original TaSST.

Changes made to the output layer were based on difficulties in the perception of the vibrotactile stimuli, that arose from the user study. Here, we considered the overestimation of the duration of received touches, as well as the difficulty in determining the surface area of a received touch. Regarding the surface area, we suspected that, in some cases, the vibration motors made the fabric sheet, made from firm felt, vibrate. This might explain why participants overestimated the surface area of some of the touches they received. To improve on this issue, we used a laser cutter to remove excess material from the sheet to which the vibration motors were attached. Our aim was to reduce the amount of vibration that could be felt through the entire surface of the output layer of the sleeve. Furthermore, we decided to place the vibration motors perpendicular to the surface of the fabric sheet. Studies suggest that placement of vibration motors in this orientation, improves the perceptibility of vibrotactile stimuli [27, 29]. Intuitively this can be understood by the fact that the direction in which the eccentric mass within the motor casing moves, is towards the skin, rather than moving horizontally over the skin. The changes made to the output layer were aimed at improving the perceptibility of the vibrations generated by the vibration motors.

Finally, all of the control hardware necessary to use the TaSST 1.5 was hidden away in a box, which connects to a PC and power socket. This was purely for practical reasons, making the TaSST 1.5 easier to set up, and less susceptible to hardware failure due to movements made by the user.



Figure 4: TaSST 1.5. In the top-left the output layer, input layer and control box can be seen.

6 CONCLUSIONS AND FUTURE WORK

In this paper we presented the initial design of the TaSST, a tactile sleeve for synchronous mediated social touch. The design was based on the idea that simple, protracted, and dynamic touches are important in social touch situations. Our goal was to assess to what extent the TaSST could be used to communicate these touch categories over a distance. Data from the user study suggests that the first version of the TaSST was most suitable for the communication of protracted touches, and simple touches respectively. For dynamic touches, considerable confusions were found when participants were asked to imitate touches they received through the output layer of the TaSST from this touch category. Based on these results we made a number of changes to the input- and output layer of the TaSST, in order to make it more suitable for dynamic touches. However, these changes are provisional, and more radical changes to the design of the TaSST might improve its use in the communication of touches from all three touch categories, even further. For example, adding additional vibration motors, and thus reducing the spacing between motors, may make the TaSST more suitable for dynamic touches that benefit from tactile apparent movement [22, 23]. Moreover, algorithms for tactile ‘anti aliasing’ [22] such as the tactile brush algorithm [20] could be implemented in order to generate believable stroking motions with the TaSST. However, a delay between input and output is expected here. It will have to be investigated what kind of impact such a delay would have on the communication of the different touch categories using the TaSST. On the input side, the size of individual sensor compartments could be reduced. This would create a higher resolution and smoother input surface that might be more appropriate for dynamic touches. Moreover, additional sensors could be added to the input layer. Capacitive sensors for instance, could be used to detect very subtle touches. Combining the data from capacitive sensors with the data from the conductive wool sensor compartments, would make the TaSST sensitive to a wider range of touches.

It has to be noted here that as a first test the TaSST was assessed in controlled conditions in a lab setting. For the first design and redesign of the TaSST it was considered important to

study the capability of the TaSST to communicate touches from the different touch categories that are relevant for specific social touch situations. However, the TaSST has not yet been studied in an actual mediated social touch setting. Future research will focus on using the TaSST as a research tool for mediated social touch settings. For example, as an augmentation during telephone, or video chat conversations [27], mediated communication through a virtual agent [1], or virtual storytelling situations [32]. Here we hope to study how touches received through the TaSST are perceived, given differing social contexts.

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