The Tickler: A Compliant Wearable Tactile Display for Stroking and Tickling

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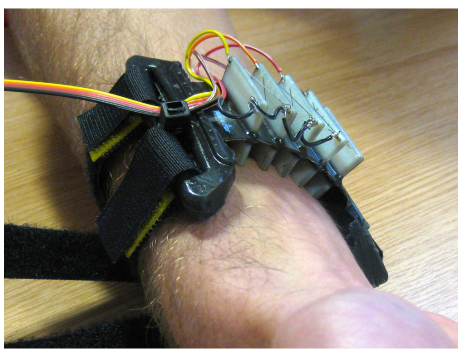

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Abstract

We present the Tickler, a compliant wearable tactile display that creates natural-feeling stroking sensations. The current state-of-the-art of tactile devices relies primarily on vibrotactile stimulation, which limits the possible sensations that can be created. There is a wide range of applications for tactile devices mimicking the sensation created by human touch, including mediated social touch and also tactile feedback applications.

The Tickler employs an array of parallel bars that slowly move laterally over the skin in different patterns. It is underactuated and compliant, so that it can move with the skin of the user. In this paper we describe the Tickler, consider possible applications and present a preliminary user study.

Author Keywords

Haptic device; Tactile Stimulation; Laterotactile; Wearable; Smart Actuators.

ACM Classification Keywords

H.5.2 [User Interfaces]: Haptic I/O.

Introduction

There is much interest in tactile communication with handheld or wearable devices, for mediated social touch as well as for tactile feedback. The tactile domain is particularly suitable for wearable devices as they are constantly in contact with the skin. The ultimate tactile display should be able to elicit a range of sensations to the user — it should mimic real-world tactile interaction.

The current state-of-the-art in handheld and wearable tactile devices relies primarily on using vibration motors to create vibrotactile sensations (e.g. [4]). This creates strong tactile sensations that can be detected through layers of clothing, however the space of possible tactile sensations that can be elicited is limited. It will always feel like a forced vibration rather than a more natural sensation.

In contrast to this, real-world tactile interactions create a huge range of different sensations including stroking, brushing, pressing, tapping and tickling. While it is possible to devise a coding scheme to encode some of these sensations through vibrotactile interactions (e.g. [11]) this is not a substitute for actually eliciting those sensations.

Here we present the Tickler, a wearable device that uses slow laterotactile stimulation to create a pleasant stroking sensation. We have initially looked at using the Tickler to stimulate the wrist, but preliminary tests have shown that it can also stimulate the calf and the back of the neck. Our design is soft and compliant allowing it to conform to the shape of the user.

Related Work

Huisman *et al* [7] present the TaSSt, a touch-sensitive vibrotactile arm sleeve for mediated social touch. They use it to mediate sensations including poking, squeezing and stroking. The ForcePhone [6] allows users to send haptic messages during phone calls by squeezing the phone, whereby the pressure is mapped to vibrations of the recipient's device. Through a month-long user study they found that augmenting phone calls with tactile communication has useful value — as a greeting, to express emotions, or to indicate presence. CheekTouch [11] uses an array of vibrating motors on the back of a mobile phone to map tactile inputs to the touch screen to tactile output. BuzzWear [9] looks at perception of vibration patterns using a wrist-worn wearable tactile display. These works show that mediated social touch has great value, however there is a need for tactile devices that can create sensations other than vibrations.

Stanley and Kuchenbecker [13] create wrist-mounted tactile displays for mimicking human physical contact including tapping, dragging, squeezing and twisting, and there are other examples of wrist-mounted skin stretching devices using rotation [1] and translation [3].

Kusuguri [5] is a visual and tactile interface for bidirectional tickling that uses a smartphone augmented with vibration motors. The sender tickles his own hand, and the receiver feels vibration patterns and sees an image of the senders hand being tickled. They found that the vibration patterns were not sufficient to create a tickling sensation. The HaptiTickler [14] is a vibrotactile device worn against the chest for creating a tickling sensation. Ants in the Pants [12] is a tactile glove that creates a sensation of ants crawling up the forearm.

Most of the above work relies on electric motors for actuation. Smart actuator technologies could allow for low-cost high-resolution large-scale tactile devices to be realised. With the Tickler, we have implemented a mechanically simple device for eliciting sensations other than vibration. We have used Shape Memory Alloy

(SMA) actuators, so the design could readily be miniaturized and scaled up to large arrays.

Applications

The Tickler could be used for mediated social touch to more closely mimic human physical contact, in particular to create pleasant tactile sensations for expressing emotion and affection. As argued by [13], the mediated tactile information should have inherent meaning; it should feel like natural touch.

In tactile feedback applications, the Tickler could be a gentle and unobtrusive means of communicating non-urgent alerts. A busy user would be able to ignore the alert without finding it annoying, but would notice the alert once their attention is free. Making non-urgent alerts more gentle could improve the user experience and would also direct more attention to urgent alerts. Unobtrusive alerts could also function as a personal alarm clock for gentle wake-ups.

For immersive experiences combining tactile, visual and auditory elements, the Tickler could be used to reinforce positive and pleasant sensations by combining it with pleasant visual and auditory stimuli. Other tactile elements could be used for creating different sensations.

Through preliminary tests we have found that the Tickler can be used on other parts of the body including the calf and the back of the leg. For patients with chronic pain, the Tickler could potentially be used to continually and gently massage and stimulate the painful area to provide relief.

The Tickler Prototype

The Tickler uses an array of tactile bars that move laterally against the skin surface. This form of

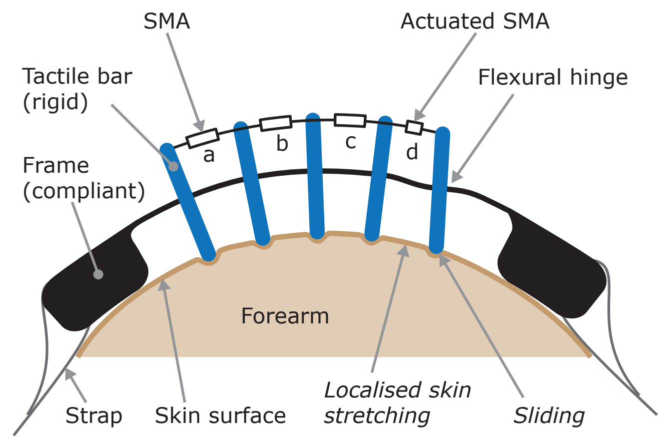

Figure 1: Schematic diagram of the Tickler. Actuation of the Shape Memory Alloys (SMAs) cause the tactile bars to move laterally against the skin, which we hypothesise causes *sliding* and *localised skin stretching*.

laterotactile stimulation has previously been used for stimulating the glabrous skin of the fingertip [8, 15], and Biggs and Srinivasan [2] argue that for the hairy skin laterotactile stimulation is preferable.

A schematic diagram of the Tickler is presented in Fig. 1. The rigid tactile bars are mounted in a compliant frame that also acts as flexural hinges. The tactile bars were fabricated from rigid photopolymer with a 3D printer (Objet 260 Connex, Stratasys, Ltd.). The compliant frame was moulded from Vytaflex 60 rubber (Smooth-On, Inc.), using a compliant mould fabricated with the same 3D printer. SMA actuators are arranged between the tactile bars so that actuation causes the respective pair of tactile bars to contract at the actuator end and to splay apart at the skin surface. This actuator layout means that

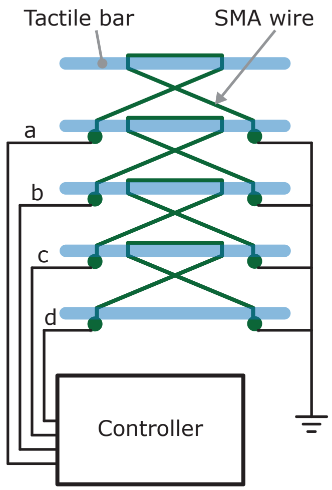

Figure 2: Schematic of the configuration of the SMA wires. The crossed pattern amplifies the movement of the tactile bars.

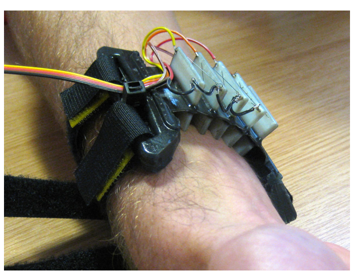

Figure 3: A user wearing the Tickler on the forearm.

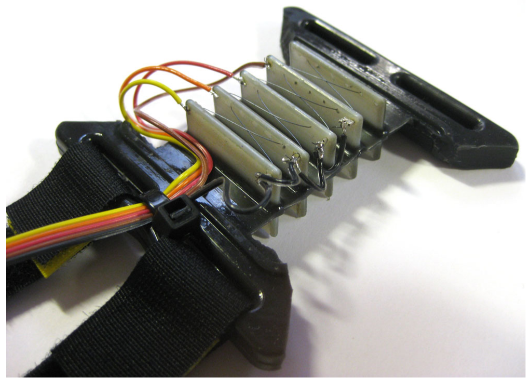

Figure 4: The developed Tickler prototype.

the movement of the bars is coupled, and that the device is underactuated. This, together with a compliant frame, means that the display will naturally conform to, and move with, the user.

SMA wire actuators contract with a relatively high force when heated. Wires are heated by passing a current through them. They are mechanically very simple, giving the Tickler very low mechanical complexity. They also produce minimal tactile or auditory noise. The response of SMAs is relatively slow ($\sim$1 s to actuate), which makes them well suited for this type of gentle tactile stroking. The SMAs contract 5 % in length when heated, and we used a crossed layout to greatly amplify the displacement of the tactile bars. The configuration of the SMAs is shown in Fig. 2. A custom driving board was developed to drive the SMAs, controlled by an Arduino Uno.

A user wearing the developed Tickler prototype is shown in Fig. 3, and Fig. 4 shows a close-up view of the device.

Tactile Stimuli

By actuating each of the SMA actuators in turn, different tactile stroking patterns can be created. Levesque *et al* look at generating stroke patterns from vector graphics [10], however this is for an array of 8×8 actuators. To create a sensation of stroking, we chose to consider travelling wave patterns moving across the device. However, there is a large space of actuation patterns that should be explored.

Fig. 5 shows some possible travelling-wave actuation patterns along with the sensation we would expect them to produce: stroking from one side to the other, pinching together and pulling apart.

Initial tests showed that actuating each SMA for 3.5 s with a delay of 1.8 s between actuating adjacent SMAs worked well for generating effective tactile stimuli.

We carried out an experiment to characterise the Tickler, and determine the resultant movement of the tactile bars when actuated. The Tickler was attached to a smooth Delrin cylinder (100 mm diameter). The actuation pattern described above was applied while videoing the experiment. The movement of the tactile bars was then extracted from the video.

The resulting displacement of the tactile bars is presented in Fig. 6. It can be seen that the actuation pattern causes a 'ripple' to travel across the device. The maximum displacement of each bar is $\sim$1 mm. It seems that each SMA has little effect on the non-neighbouring tactile bars: the central bar is not affected by actuator *a*. The displacement of the outer bars is greater than the central bars, as the outer bars are less constrained.

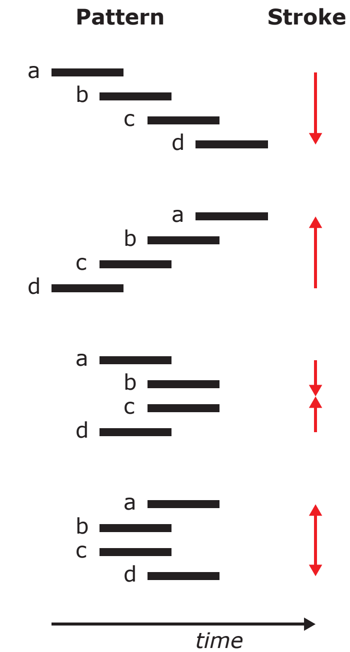

Figure 5: Some possible actuation patterns and resulting strokes.

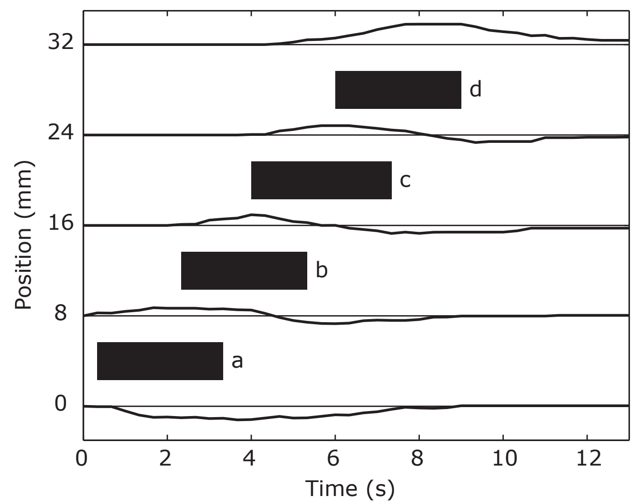

Figure 6: Displacement of the tactile bars for a stroke travelling across the device. Black boxes indicate actuation of the respective SMA wires.

As the device is underactuated, the movement of the bars will be different for different users, however Fig. 6 is a good indicator of the output of the device.

User Study

A formal user study was undertaken to find what sensation the Tickler creates, and determine if it could be used to present tactile information through actuation patterns.

11 volunteers (2 female), with a mean age of 26, participated in the study. Participants were told that we were interested in tactile devices creating different sensations, but were not given cues as to what type of sensation to expect. Participants were presented with 10 consecutive stimuli travelling across the device, as shown in Fig. 6, and were asked if each stimuli moved from right to left or from left to right. Apart from one participant, performance was very good with 90 % correct responses. The outlier participant had 10 % correct responses, suggesting that the tactile information was perceived but consistently mis-labelled. This shows that the Tickler could be used for conveying tactile information through actuation patterns.

After the trials, participants were prompted to *'describe in your own words what the stimuli feel like'*. The key phrases from the comments have been included in Table 1. It can be seen that participants described the sensation as pleasant, and natural rather than artificial and mechanical. One participant described it as 'a subtle tickling sensation'.

Discussion

The Tickler creates gentle and comfortable stroking and tickling sensations that are very different from the vibrotactile stimulation typically used in tactile devices. The design of the device is mechanically simple, and it could readily be miniaturised and integrated into watch straps or other wearable devices. If multiple synchronised Ticklers were worn on different parts of the body, then full-body tactile gestures and patterns could be presented to the wearer, creating exciting opportunities for future research.

Much work remains in exploring the possible space of tactile stimuli that can be created and determining the sensitivity thresholds for different types of stimuli. We believe that the Tickler works by the tactile bars sliding against the skin, but a more in-depth study to investigate the underlying mechano-sensory mechanism by which it works is under way. This could give some understanding

Table 1: User Comments

'A subtle tickling sensation'
'Like a caterpillar rolling over the skin'
'Feels good'
'Not mechanical'
'Soft pressure'
'Like a massage'
'Comfortable'
'Grips your arm'
'Gently pressing from one side to the other'
'Like it is underneath the skin'
'Pushing moving across'
'Like a strange massage'
'Soft object pushed against you'
'Low-intensity pins and needles'
'Travelling pressure'
'It feels good'

as to which element of the stimulus is responsible for creating the stroking and tickling sensation.

There is a vast range of natural tactile stimuli, and the Tickler represents a new piece in the puzzle of creating tactile devices that interact with us in natural and comfortable ways.

Acknowledgements

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