Texture Displays: A Passive Approach to Tactile Presentation

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ABSTRACT
In this paper, we consider a passive approach to tactile presentation based on changing the surface textures of objects that might naturally be handled by a user. This may allow devices and other objects to convey small amounts of information in very unobtrusive ways and with little attention demand. This paper considers several possible uses for this style of display and explores implementation issues. We conclude with results from our user study, which indicate that users can detect upwards of four textural states accurately with even simple materials.

Author Keywords
Texture displays, tactile, smart materials, persistent, passive, textiles, fabrics, inexact and inattentive interaction.

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION
Tactile stimuli have several unique qualities (see, e.g., [3,5,8,11] for details). They are often employed to reduce visual and/or auditory attention demand because they operate in a separate perceptual channel. Also, unlike auditory and visual information, which typically propagate over long distances, tactile stimuli generally need to be proximate to the user (i.e., touching). This means information can be delivered to a single user, without disturbing others nearby.

Despite touch being a rich sensory channel [5,8], tactile displays are almost exclusively vibrotactile in nature. Actuation is typically achieved with small vibratory (spinning) motors, like those found in cell phones, or piezoelectric buzzers. Although inexpensive and easy to deploy, these techniques have several significant limitations. First, noise is a common byproduct from the physical vibration of the device – it is not uncommon to hear a cell phone chattering on the surface of a table or against keys in someone's pocket. This makes them more socially intrusive and potentially more attention demanding than they might otherwise be. Second, vibrotactile alerts are generally limited to short bursts of actuation (e.g., vibrate when there is an incoming call). They are not employed to persistently relate a state (e.g., a missed call). This is primarily because they are an *active* output technology – when on, they produce a stimulus to alert the user. To display a persistent state, they would have to be permanently active. However, not only would this be highly irritating and distracting to the user (e.g., a persistently vibrating sensation), but also prohibitively expensive power-wise for mobile devices.

To overcome some of these limitations and expand the possible design space for tactile output, we explore displays that can assume several different textural states (e.g., sticky, bumpy, smooth, course, gritty). In contrast to conventional vibrotactile approaches, these displays provide information *passively*. Only when they are explicitly handled by the user, either with intent to inquire about the information, or in the course of some other action, can state be sensed. This inherently reduces their attention demand and intrusiveness. We call this class of devices *texture displays*.

TEXTURE DISPLAYS
Table 1 illustrates the fundamental difference between texture displays and conventional vibrotactile stimulation. In the later modality, the user is passive, waiting to receive input - the user does not initiate the exchange of information. Instead, vibrotactile elements actuate in response to some change (e.g., incoming call) and actively stimulate the user. Texture displays, however, assume the opposite behavior. The device waits there passively, persistently displaying a particular texture. Now, the user assumes the active role, initiating information exchange by touching the device. Furthermore, the physical motion necessary to covey the state comes from the user and not the device. In other words, instead of the display being active and the user passive, as is the case with vibrotactile alerts, texture displays are passive while the user is active.

This unique behavior introduces both new opportunities and limitations. Foremost, the passive nature of texture displays

	Display	User
Vibrotactile	Active	Passive
Texture Displays	Passive	Active

Table 1. Vibrotactile and texture displays, although both tactile in nature, are distinctly different in how they convey information to users.

prevents them from fully utilizing the temporal dimension to increase their expressiveness (e.g., texture change over time), something vibrotactile patterns rely on heavily [4]. Additionally, their passive nature also makes them ill suited for quickly alerting users – another area vibrotactile stimulation excels at. However, texture displays enable persistent information display and allow users to initiate interaction, which vibrotactile feedback cannot achieve easily.

EXAMPLE APPLICATIONS

We present three example domains where texture displays could be easily, unobtrusively and usefully integrated into the user environment. These not only help illustrate the utility of texture displays, but also demonstrate some of the new opportunities enabled by the technique that could not be pursued with pervious tactile approaches.

Mobile Devices

The ability to unobtrusively and persistently display state information opens the possibility of, for example, new mobile phone interactions. Consider a cell phone with the ability to alter the texture of its enclosure. Now, a user could check if there has been a missed call or outstanding text messages, simply by reaching into their pocket and passing their hand over the exterior of the phone. This requires no visual attention, and thus can be done without "getting out" the phone, which can have deleterious social effects if engaged in conversation, in a meeting, or any number of other social situations.

Visually Demanding Activities

There are many activities that consume our visual attention. Driving is one such activity, and considerable HCI research has focused on reducing attention demand (especially visual) to improve its safety (e.g., [1,7]). The steering wheel, for example, offers an obvious opportunity for textual augmentation, as engagement with that surface is mandated by the task. Texture displays could also be applied to gear shifters, indicator controls, motorcycle handlebars, aircraft yokes, crane levers, and a wide range of other control interfaces. These surfaces could persistently relay information, for example, about speed, driving performance, fuel consumption, remaining fuel, time to destination, upcoming traffic conditions, weather forecast, road surface conditions, and any number of other non-time-critical and persistently-variable information. This type of interaction cannot be achieved with vibrotactile techniques (e.g., [4]) or the pneumatic steering wheel setup described in [7].

Grasped Objects Along Habitual Paths

There are many surfaces we interact with during our everyday routines. Many interesting opportunities arise if we have the ability to unobtrusively insert one or two bits of information into these interactions. For example, a user entering his or her office in the morning could be alerted to the presence of outstanding voicemail messages by a two-state doorknob (e.g., smooth or rough). Additionally, a chair could be outfitted with variably-textured armrests. This could allow, for example, to unobtrusively convey to the user that they have another appointment in less than five minutes. One can imagine how useful this could be during a series of meetings, where one would typically have to glance at the clock repeatedly – generally socially obtrusive – to know when to wrap up. The refrigerator door handle offers another example. This surface could relay information about milk nearing expiration, the need to go shopping, or to remind the user to check the calendar pinned to the door. Texture displays are well suited to these oft, but randomly encountered surfaces, where they can sit passively until a user initiates contact.

INTEGRATION AND ACTUATION

In general, any material capable of changing texture is suitable for texture displays - the concept is not wed to any particular implementation or technology. However, the method employed must be sufficiently small to enable integration into everyday items (e.g., doorknobs, cell phones). Additionally, if ever to be successfully deployed, the displays have to be robust, pleasant to touch, inexpensive to manufacture, quiet in operation, and in many cases, low-powered. These requirements, in addition to the necessity for passive and persistent information display, tend to weigh against the use of other present tactile technologies. These include pneumatics [7], piezoelectric elements [11], ciliated surfaces [6], active magnetic levitation [2], and pin matrices [12], (see, e.g., [3] for more comprehensive overview of tactile technologies).

Over the course of several months, we considered dozens of candidate approaches. These required a variety of actuation methods, including linear actuators, heat, voltage, and magnetic fields. We briefly discuss the most promising materials and technologies for the construction of texture displays.

Shape Memory Materials

Shape Memory Materials (SMMs) are perhaps the most promising future candidates for texture displays. Available as cords (for weaving into other materials) or thin strips, these materials actuate themselves into different lengths, shapes, or textures in response to an external stimulus. Without the need for an external actuator, these have the potential to deliver on the ultimate promise of surfaces coated with a texturally dynamic film.

Shape Memory Alloys (SMA, also known as muscle wires) are the most common variety at present. Unfortunately, they are actuated by heat (e.g., 50°C), which is problematic as users need to touch the material. However, recent breakthroughs, especially in the area of smart polymers (SMP, EAP), have introduced new forms that react to particular frequencies of light, chemical changes, and magnetic fields (although most remain confined to the lab at present). Although some commercial applications are available (we experimented with several SMA-based motors, including the MigaOne actuator shown in Figure 1), they are not presently available in sizes or form factors suitable for direct use as texture displays (e.g., a thin film that could cover a cell phone that wrinkles when a small voltage is applied).

Smart Fluids

Electro- and magneto-rheostatic fluids change their shape or viscosity in response to a magnetic field or electric current, offering many interesting tactile opportunities. Unfortunately, the deformable skin needed to contain the liquid poses serious durability challenges for real-world and extended use. Additionally, generating a sufficiently intense magnetic or electrostatic field is problematic for use in small mobile devices and even in most home, office and automobile domains.

Piezoelectric

Piezoelectric materials are also likely to prove useful in future texture displays. This class of material deforms in response to an electrical current, a convenient actuation form for electronics. Unfortunately, deformation is small, typically less than a millimeter. Although it is possible to layer many elements together to increase this distance [11], the resulting bulk, cost, and actuation voltage makes the technology premature for effective integration into texture displays at present. However, this technology continues to advance - touch screens utilizing piezo elements to create areas with increased friction (e.g., for on-screen buttons) will soon be released [9]. If these areas can be patterned in a structured way, the technology will offer the first true platform on which texture displays can be deployed.

Fabrics

Although simple, fabrics have several advantages over more complex materials - they are inexpensive, thin, robust, pleasant to touch, visually appealing, and easily customizable. However, to be variably textured, they require an external mechanical actuator (to stretch the material), which poses a significant integration obstacle. Fortunately, a number of miniature actuators are now available that are suitable for this purpose. We experimented with several actuator types, including conventional servo and rotational motors, as well as SMA-based linear actuators and servos. These provide a range of options for feasible fabric-based implementations immediately, as well as starting points from which a more customized actuator could be developed if needed.

As a proof-of-concept platform, we embedded a flat MigaOne linear actuator [10] into an acrylic enclosure matching the dimensions of a second-generation (3G) Apple iPhone (Figure 1). The MigaOne actuator is constructed with SMA wires, which contract when heated by a small electrical current. Its components are mounted on a conventional flat circuit board as seen in Figure 1. Test fabrics were attached to the enclosure with two small bolts – one attached to the acrylic enclosure (fixed) and the other to the linear actuator. This allowed materials to be stretched from 26 to 35mm, a stretch coefficient of 35% – sufficient to actuate our test fabrics.

Beaded Matrices

We also considered matrices of beads, which, during our investigations, proved to be texturally dynamic and physically robust. These can be fabricated by either sewing beads onto an elastic substrate (e.g., rubber sheet, elastic strap), or by weaving them together with elastic cord (similar to how many beaded bracelets are manufactured). Two different textural configurations can be achieved. First, beads can form ridges in the relaxed state and become smooth when stretched (i.e., pull out the "wrinkles"). Conversely, beads can be in a smooth configuration when relaxed, and become spaced out when stretched, creating gullies (see Figure 2, Beaded Matrix).

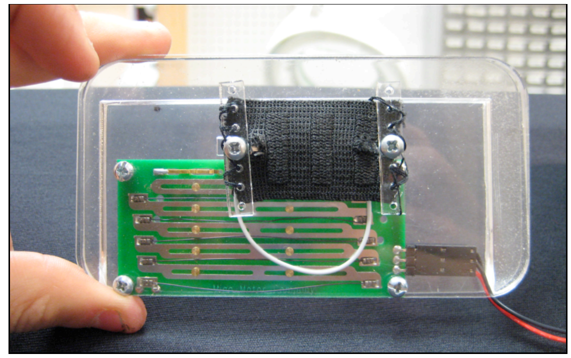

Figure 1. A prototype device built with a MigaOne linear actuator embedded in iPhone-scale acrylic enclosure. Test materials were fixed at one end, and actuated on the other.

EVALUATION

After considering a range of implementation approaches, we strongly believe that texture displays could be successfully produced with present technologies and certainly with forthcoming ones. However, it remained unclear how much information could be conveyed to users by texture alone. Thus establishing an approximate lower bound of users' textural discrimination was vital to resolve if texture displays were to be shown to have any feasibility.

To assess this, we conducted a preliminary user study that investigated participants' ability to detect and name several different textural states. As noted before, texture displays transcend any particular material or technology. To simplify our evaluation, we rely exclusively on materials that can be actuated mechanically (i.e., stretched), since these could use a common actuation platform and were readily available, safe to touch, inexpensive and robust. Although simple, these materials were sufficient to answer the central question of whether or not texture could be used to convey state.

Six materials were selected for the study (Figure 2). In addition to using a beaded matrix, we also selected five materials from three classes of fabrics we had identified. The first type of fabric was woven elastic, which tended to have striated features that spread out when stretched. We also found that certain varieties of Spandex increased in textural friction when under tension. Our final class of fabrics took inspiration from elastic straps found on clothing, especially waistbands. These are typically composed of two materials; a non-stretchable fabric superimposed onto an elastic substrate. We duplicated this effect by stretching a section of elastic strap and sewing on a secondary material (e.g.,

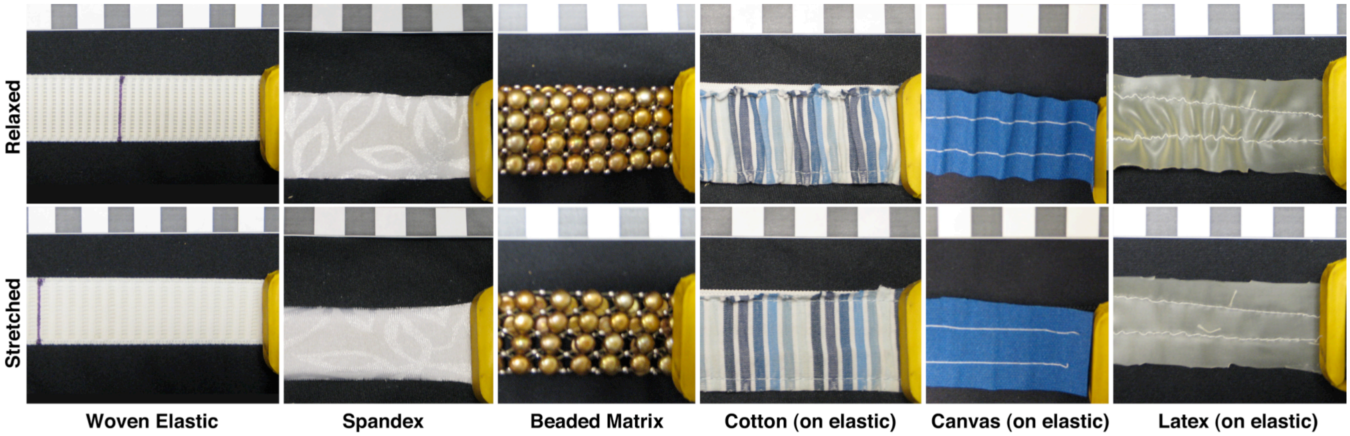

Figure 2. The six materials evaluated in the user study, shown here in relaxed and fully stretched states.

denim, leather, felt). When the elastic is allowed to retract, the secondary material bunches into a series ridges. When stretched, the secondary material returns to a flat (smooth) state. One can control the frequency and amplitude of these ridges by manipulating the initial elastic stretch and the stitch spacing.

We recruited 15 participants (8 female) with mean age of 28. Participants were paid ten dollars for their involvement in the study, which took approximately one hour. Each of the six test materials was presented to participants with two, three and four states of stretch (random order). Naming of the states was left to participants, with some preferring descriptions, and others, numbers (e.g., 1, 2, 3 and 4 in the four-state case). Before each round began, participants were allowed to feel the texture of each of the states in order to train (one minute maximum). Following this, each state was presented three times in a random order. Without looking, participants had to name which state the material was in. In total, 2430 responses (162 per participant) were collected.

RESULTS

Participants were able to achieve surprisingly high levels of accuracy despite almost no training (Figure 3). The woven elastic sample performed the worst, yielding 80% accuracy at two states. By four states, accuracy dropped to 52% - clearly too low for any practical application. However, the canvas- and latex-on-elastic samples performed at greater than 80% even at four states. At two states, both materials boasted 100% accuracies. We believe this result clearly demonstrates that one or two bits of information can be reliably transmitted via texture. Additionally, having used

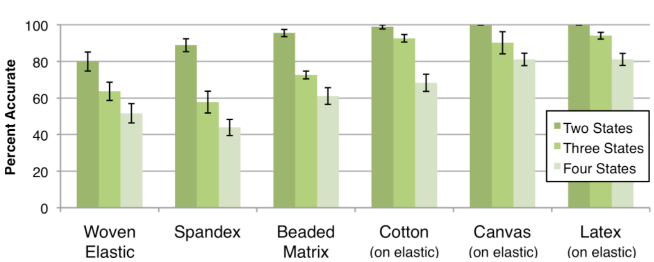

Figure 3. Average recognition accuracy of the six test materials at two, three and four textural states.

fairly generic materials, we strongly believe superior and specifically design materials would likely yield better results.

CONCLUSION

We have presented a new class of tactile devices called texture displays. This passive technique offers a distinctly different interaction behavior than that of conventional vibrotactile stimulation. Results from our user study indicate that even simple materials can reliably convey one or two bits of information via textures to users. We hope this result will encourage practitioners and researchers to consider new avenues and opportunities for tactile integration.

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