Super *Cilia* Skin:
A Textural Interface

Abstract

The Tangible Media Group has done a series of investigations into new multi-modal computer interfaces that utilize gesture and the sense of touch to improve interpersonal communication, education, and access to digital information. "Interactive surfaces" are one of our most promising lines of research and this article will look in depth at the design, implementation, and possible applications of interactive surfaces through an example project, Super Cilia Skin, an Interactive Membrane.

Super Cilia Skin (SCS) is a computationally enhanced membrane that couples tactile/kinesthetic input with tactile and visual output. Our prototype manipulates the orientation of an array of yarn-like actuators (cilia) to display dynamic images or physical gestures. Like cloth, SCS is designed to be applied to arbitrary objects to engage sight and touch. Unlike traditional textiles, SCS can sense touch and dynamically move its surface. This article will discuss the potential for scale shifts with actuated textiles in which the material can blur boundaries between foreground/environment and field/object. Our design studies will present applications in which actuated textiles can use their material properties to improve interpersonal communication, enhance creative expression, and assist education in young learners by engaging tactile/kinesthetic intelligences.

HAYES RAFFLE, HIROSHI ISHII AND JAMES TICHENOR

Hayes Raffle is researching tangible interfaces at the MIT Media Lab. He is developing materials with memory and researching their applications to education and the arts. Before attending MIT, he studied sculpture at Yale College, and codesigned the award-winning ZOOB® building toy.

James Tichenor is conducting research in Design and Computation at the MIT School of Architecture. His current investigations address issues of architectural surface with digitally manipulated materials. Before attending MIT, he worked for Konyk Architecture and cofounded FourPlus Design.

Hiroshi Ishii's research focuses upon the design of seamless interfaces between humans, digital information, and the physical environment. He is a tenured associate professor of Media Arts and Sciences, at the MIT Media Lab. To pursue his vision of "Tangible Bits," Professor Ishii founded the Tangible Media Group at the MIT Media Lab at the end of 1995.

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Super *Cilia* Skin: A Textural Interface

Introduction

For thousands of years people have sought to design environments, tools, and objects to define their context in the natural world. Man-made objects such as buildings and clothing are designed as boundaries between the body and the natural environment, whereas art objects are often created for emotional reflection or communication. The surge of computers in the last half-century has led to a variety of research that intends to find both meaning and context for a world filled with "intelligent" machines. Where some have created tools to improve human productivity, others have explored philosophical and aesthetic investigations through the creation of interactive art works and responsive environments.

Figure 1
SCS conceptual rendering.
Photo: Mitchell Joachim,
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The Tangible Media Group at the MIT Media Lab conducts research in "Tangible Interfaces" with a vision to improve people's access to computers by creating computational media that take advantage of existing skills people have developed through working with physical objects (Ishii and Ullmer 1997: 234). These platforms and digitally enhanced objects aim to bridge the intangible world of digital information with the physical world.

As part of our ongoing research we developed a prototype textural interface called Super Cilia Skin (SCS; Figure 1). SCS is an interactive membrane designed by Hayes Raffle, James Tichenor, and Mitchell Joachim that allows two people to communicate over a distance by manipulating the orientations of an array of yarn-like actuators (Raffle 2003: 529). SCS metaphorically interprets biological "skin" as an actuated, sensory interface between a computer and its environment. Skin is protective, sensory and tactile, touch being our only sense capable of both sensing and manipulating the environment. Applying this metaphor across multiple scales allows one to imagine a skin that can clothe small objects, the body, or the environment. This is similar to traditional textiles, in which material can transcend scale to engage people, touch, material, and environment, the difference being that a digital textural interface provides a gateway to information technology.

In this article, we consider the many opportunities afforded by an interactive membrane and address how a tactile material could both represent and provide the ability to create information. Reflecting upon our experiences designing and testing our prototype, we will discuss possibilities with actuated textiles as a benefit to children's learning, interpersonal communication, and architectural design. Since we created SCS to be a material available to designers, this article will begin with an overview of the development of our prototype and will then explore potential applications for actuated textiles by drawing on examples from various fields of study.

Figure 2
Images of wind blowing over grassy fields inspired SCS. Photo: Hayes Raffle, © 2003 Hayes Raffle.

SCS

SCS is a tactile and visual system inspired by the beauty of grass blowing in the wind (Figures 2 and 3). It is made of an elastic membrane covered with an array of felt actuators (cilia). These cilia move in response to computer-controlled magnetic fields created under the membrane, allowing them to represent information by dynamically changing their physical orientation (see Figure 12). The device is designed to sense physical gestures on the cilia and to replay those gestures by wiggling the same cilia that were touched. Because SCS converts gesture to computer data, multiple Super Cilia Skin devices may communicate over a distance using a standard computer network. For example, where a telephone allows

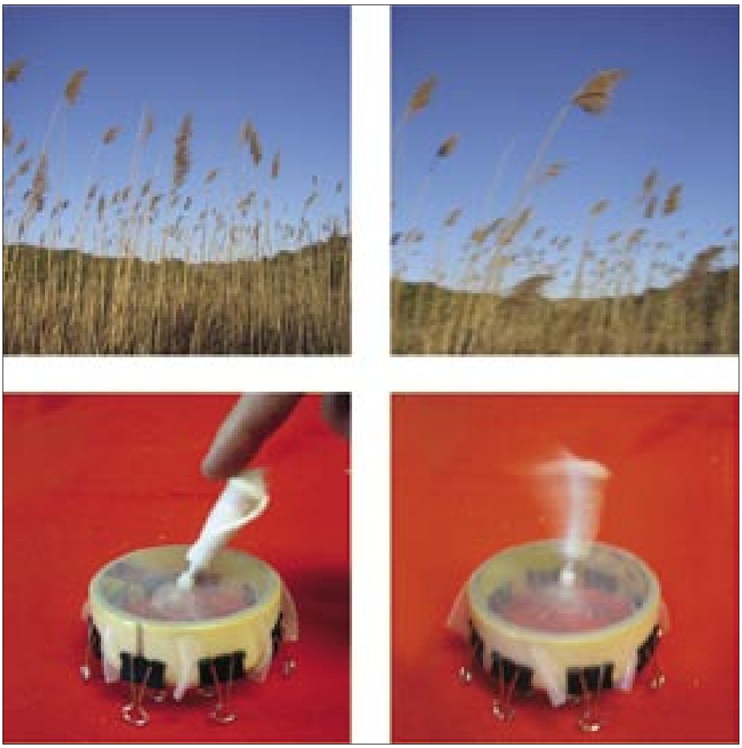


Figure 3
The movements of grass are re-created with felt actuators in an elastic membrane. Photo: Hayes Raffle, © 2004 Hayes Raffle.

two people to talk to each other over a distance, two SCS devices may be used to communicate remote gesture (Brave *et al*. 1998: 169). Similarly, the system can be used alone to display previously recorded information.

While our current prototype functions only on a table top, our studies suggest that creating a scalable, tactilely expressive fabric may be possible. This fabric would record and playback physical gestures on its surface or synchronize motions across two paired objects to support intimate physical communication.

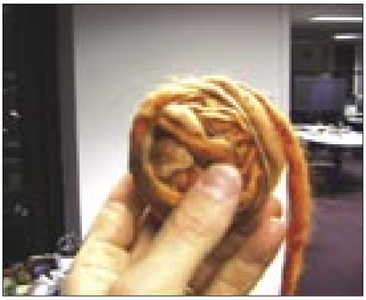
Design Process

The development of SCS was guided more by aesthetic decisions chosen for their appeal to us as artists and designers, than by engineering decisions chosen to create an optimized performance. This approach contextualizes a type of research that focuses on the history and chronology of craft. The craft tradition embodies a history of people who have a knowledge of how things are made and how to make things with which people intimately interact. This was an important foundation for our development of SCS because computer technology has traditionally been developed either as engineering with a clear solution, or as art whose value cannot be easily measured.

In the design of SCS we built upon existing tangible interface research and used the concept of scale to expand this work in new ways. In the history of tangible interfaces, materials are rather rare. While "Tangible Bits" described a vision for interactive surfaces (Ishii and Ullmer 1997: 234), most tangible interfaces have been presented as tools or design objects with specific purposes. From its conception, SCS was intended to be a scalable, multi-modal material that could transmit meaning through tactile and visual movement.

The term *cilia* refers to microorganisms such as paramecium that use small hair-like structures—cilia—for locomotion. By moving these cilia in rhythm, these animals are able to move through fluid, not unlike a boat with many people rowing. There has been research in the MEMS community to use microscopic man-made cilia for locomotion (Suh *et al*. 2000: 1101). Changing the scale of the cilia to that of the hand or body changes the cilias' function and the ways that people can interact with them.

Many metaphors for macro-scale cilia fill our environments. Wind-swept grass, vacuum-cleaner tracks on shag carpet, mowed baseball fields, and kinetic sculptures all influenced our understanding of the concept of a textural field. Many of these cilia oscillate with different mechanisms. For instance, the San Francisco Exploratorium presents a gravity-powered field of undulating pendulums that oscillate in response to one's touch (Fleming 1980). The top surface of these oscillating pins describes movement across a horizontal plane. This oscillatory mechanism is fundamentally different than microscopic sensory hairs in our ears that convert air movements into hearing. These hairs are anchored in the tympanic membrane of our ear canals, and their static orientations are maintained by the elasticity of the membrane. This mechanism inspired an elastic membrane for SCS, in which macro-scale cilia can cover curved surfaces and have consistent behaviors independently of gravity.




Figures 4 and 5
Wool yarn inspired the tactile and visual qualities of our prototype cilia. Photo: Hayes Raffle, © 2002 Hayes Raffle.



Figures 6, 7, and 8
Prototypes tested different materials, cilia densities, and aspect ratios. These used cotton swabs and plasticized vinyl. Photos: Mitchell Joachim, © 2002 Mitchell Joachim.

Design Evolution

Looking to examples of textural metaphors in our environments, we tested a variety of materials for prototype cilia, including yarn, cotton batting, wool rope, wire chenille, natural twigs and leaves, pom-poms, and bottle brushes (Figures 4 and 5). Our earliest prototype used cotton swabs anchored in a highly plasticized vinyl membrane (Figures 6, 7 and 8). By gluing small magnets to the bases of these swabs, we found we could easily control their general orientations with a separate magnet. The softness of the swabs encouraged people to put the prototype next to their faces, describing the sensation as similar to the "butterfly kiss" created when someone transmits a gesture with one's eyelashes.

Magnetic fields allowed us easily to create force fields on the cilia that dispersed with distance in a manner similar to wind (Figure 9). The Actuated Workbench (Figure 10) allows a computer to "draw" with magnetic fields (Pangaro *et al*. 2002: 181), and our prototypes employed various densities of cilia that converted these magnetic fields into mechanical movement (Figures 11 and 12).

Our early design studies explored density and aspect ratio of the cilia and their tactile responses when anchored in various kinds of membranes. Looking to existing examples of textures and natural fields, we found consistent relationships between field and object: a forest, like a tree or a shrub, appears as both surface and structure when viewed at different distances. From an airplane, one notices the surface of the forest canopy. However, as one descends towards the individual trees one notices that tree trunks bifurcate into branches and branches divide into twigs to end with leaves. The change from field to object is an abrupt perceptual shift.

We compared these visual perceptual changes to our tactile perception of material texture. By creating both three-dimensional computer models and physical models (Figures 13 and 14), we were able to quickly test different shapes and scales of cilia to establish an aesthetically satisfying balance between surface and texture. Since our prototype was designed to be manipulated by people's hands,

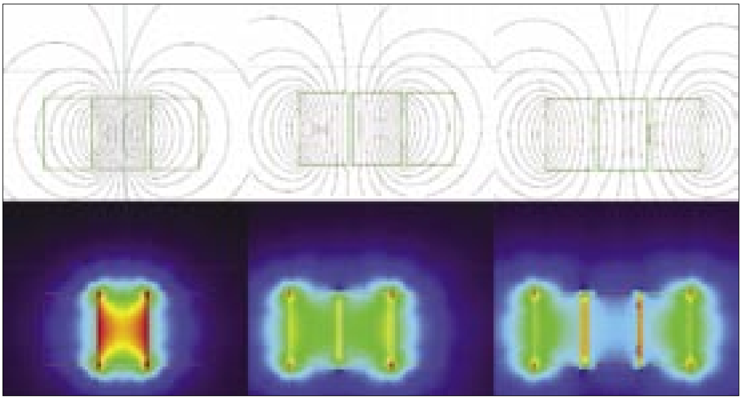
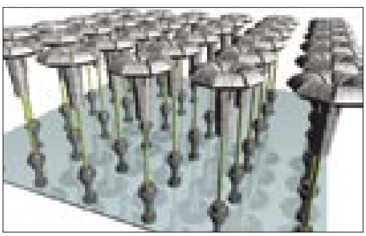


Figure 9
The interactions of the magnetic fields of Actuated Workbench combine and disperse with distance replicating the interactions of wind across a field. Photo: Gian Pangaro, © 2002 MIT Media Lab.

Figure 11
SCS Prototype on top of the Actuated Workbench. Photo: Hayes Raffle, © 2004 Hayes Raffle.

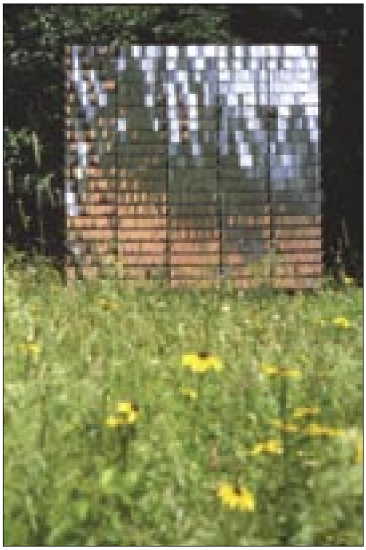
Figure 10
The Actuated Workbench. Photo: Hayes Raffle, © 2004 MIT Media Lab.

Figure 12
SCS prototype "draws" with magnetic fields. Photo: Hayes Raffle, © 2004 Hayes Raffle.



Figures 13 and 14
Various 3D renderings addressed issues of scale, relationships to natural forms and mechanical stability. Photo: Mitchell Joachim, © 2002 Mitchell Joachim.

we chose to make our prototype's cilia slightly smaller than our fingers and to space them with about 50% density. This gave the material a familiar "feel," as well as a perceptual balance between surface, volume, and tactile depth.



Figures 15
Tim Prentice's Square Wind Frame converts wind into fluctuating reflections of the earth and sky. Photo: Tim Prentice, © 1980 Tim Prentice.

History of Physical Displays

While actuated displays are a traditional focus of research in the haptics community (Wagner *et al*. 2002), SCS was inspired by artistic and architectural investigations into kinetic surfaces. A recent surge in kinetic sculpture and computer-controlled installation has allowed a variety of artists and designers to use form to depict dynamic change in novel and surprising ways. For instance, architect and kinetic sculptor Tim Prentice uses wind as a driving mechanism for "Wind Frame," a grid of galvanized steel panels that oscillate in the wind (Figure 15). These panels variably reflect the sky and ground towards the viewer, revealing the waves of wind around the viewer. Tactile wind and visual sky converge in the Wind Frame with a mechanism at once simple and sophisticated.

In a similar vein, sculptor Danny Rozin created "Wooden Mirror," a technologically driven array of wooden blocks that change orientation to create a pictorial "reflection" of the viewer of the piece (Figure 16). Wooden Mirror

Figures 16
Danny Rozin's Wooden Mirror uses live video data and servo motors to reflect the viewer and his environment in an array of motorized wooden blocks. Photo: Daniel Rozin, © 2000 Daniel Rozin.

points a video camera at the viewer and drives many small motors to angle carefully the array of wooden blocks, controlling the depth of shadows on the surfaces of the blocks. Where Prentice's Wind Frame is a formal and visual translation of natural phenomena, Wooden Mirror is more a translation of digital phenomena: Rozin has turned humble wooden blocks into "pixels" that can create a reflection of almost anything digital.

Rozin's mirror is built at a figurative scale, framing the body and its environs. An architectural extension of an actuated mosaic was explored by Goldthorpe with the "Aegis Hyposurface," a sculptural investigation into visual representation and kinetic architecture (Burry 2003: 18). While the Hyposurface has a skin similar to Prentice's Wind Frame, it draws its energy from a grid of pneumatic pistons behind its reflective steel scrim. Due to its construction, the Hyposurface naturally creates wave-like undulations when its pistons "draw." In addition to being a visual display, it is a physical and aural intrusion into a space, an active wall that temporally protrudes into the room that it helps to define. While its drawings are not triggered by immediate environmental stimuli, Aegis Hyposurface exhibits the potential impact of actuated skins built at a tectonic scale.

SCS builds on this history of kinetic displays and adds the element of tactile input, transforming the kinetic display into a tangible interface. This shifts material from a role of strict representation to a means to project human intention into the machine. Material can therefore facilitate a form of gestural "programming" that opens up surprising design possibilities.

Kinesthesia and Education (Touch and Toys)

A potential value of tangible information interfaces is their connection to our bodies, our senses of touch, and kinesthesia (Figure 17). As well as being aesthetically engaging, physical experiences have important roles in learning. Toys and educational tools helped inspire the design of SCS, and we believe that actuated textural interfaces could add beneficial qualities to existing educational tools and support existing educational practices.

The potential for textiles and texture to support children's learning is evident when one looks around a typical American infant/toddler nursery. Colors and textures abound, from textured foam books to teething objects to plush teddy bears and other

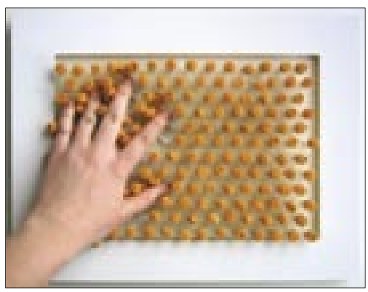


Figure 17
SCS adds a skin-like sense of touch to a visual material creating a tangible interface to computational information. Photo: Hayes Raffle, © 2004 Hayes Raffle.

stuffed toys. In the design of young children's toys, great care is given to the tactile qualities of materials. As we researched familiar instances of textures in our daily lives to develop SCS, we found the highest number and most distinct "textural signatures" among children's toys.

The prevalence of texture in children's artifacts can be traced back to the cognitive, social, and educative roles that physical interactivity with objects holds for children. Movement occupies a central position in human activity (Laban 1975 [1956]) and it is a central feature of early learning (Piaget 1952). Recent studies in children's education have argued that children have a separate bodily intelligence that includes masterful coordination of their body movements and the ability to manipulate objects in a skilled manner (Gardner 1983). Bodily kinesthetic intelligence may, in fact, be central to academic learning (Seitz 1992: 35).

Frederick Froebel's Kindergarten provides an early and important instance of specialized objects in education. Froebel distilled his worldview into a number of kindergarten "gifts," physical objects that children used in daily lessons to learn about common forms and processes found in nature. The kindergarten gifts had a deep influence on twentieth-century art. For instance, Frank Lloyd Wright credited kindergarten as the basis for his aesthetic vocabulary, and many of his architectural forms are similar to artifacts from the kindergarten classroom (Brosterman 1997: 138). Such evidence shows the strong influence educational objects can have on children's aesthetic development.

Physical materials can also help children develop skills manipulating abstract concepts. Educational manipulatives are toys that are specially designed to help children with this. For example, "Cuisinaire rods" allow children to explore the abstract concepts of arithmetic by manipulating concrete, physical blocks of different lengths. By arranging blocks to create series of equal length, children can discover that $1+3=2+2$.

While the use of physical materials in education has a rich history in the last century (Brosterman 1997: 21), the introduction of computers to classrooms has focused on screen-based activities. In an effort to develop an alternative to screen-based computer activities, Mitchel Resnick presented "Digital Manipulatives," arguing that interactive, programmable materials can take advantage of the privileged role of physical, tactile material in children's education while using computers to make certain complex ideas accessible to them (Resnick *et al.* 1998: 281). Where wooden blocks allow kids to make towers that fall over, and thus understand static structures and gravity, programmable blocks may allow kids to understand concepts like feedback and emergence in closed systems, concepts that are not usually taught until college age. Computers, coupled with physical manipulatives, can therefore help children to understand ideas that educators previously considered too complex for them (Resnick *et al.* 1998: 287).

One outcome of this work is the development of computer interfaces that are programmed through physical interaction, and some of these projects have explored the idea that material can have memory. For example, "Topobo" is a building toy with kinetic memory that can help children aged seven and older to learn about dynamic balance (Figure 18). Topobo is akin to building systems like LEGO® or ZOOB® that kids can use to make imaginative creations. The difference is that Topobo has motorized parts that can repeat the motions a child has made to them. To use Topobo, a child may snap together parts to create a fanciful animal, teach their animal how to walk by physically manipulating its bodily movements, and then observe the animal walk on its own. Topobo allows children aged 7–13 to experiment with concepts like dynamic balance and system coordination (Raffle *et al.* 2004: 875). Topobo is a scalable, modular, actuated system with which other people design objects, and thus shares conceptual "material qualities" with SCS.

A textural information interface may allow children to explore certain abstract concepts through physical manipulation of a material. Interaction with a teddy bear is typically physical interaction with the bear's material properties; bears that are soft, squishy, and textural are often chosen for those qualities. A natural design evolution is to use those same material qualities to interact with a "smart" teddy bear.

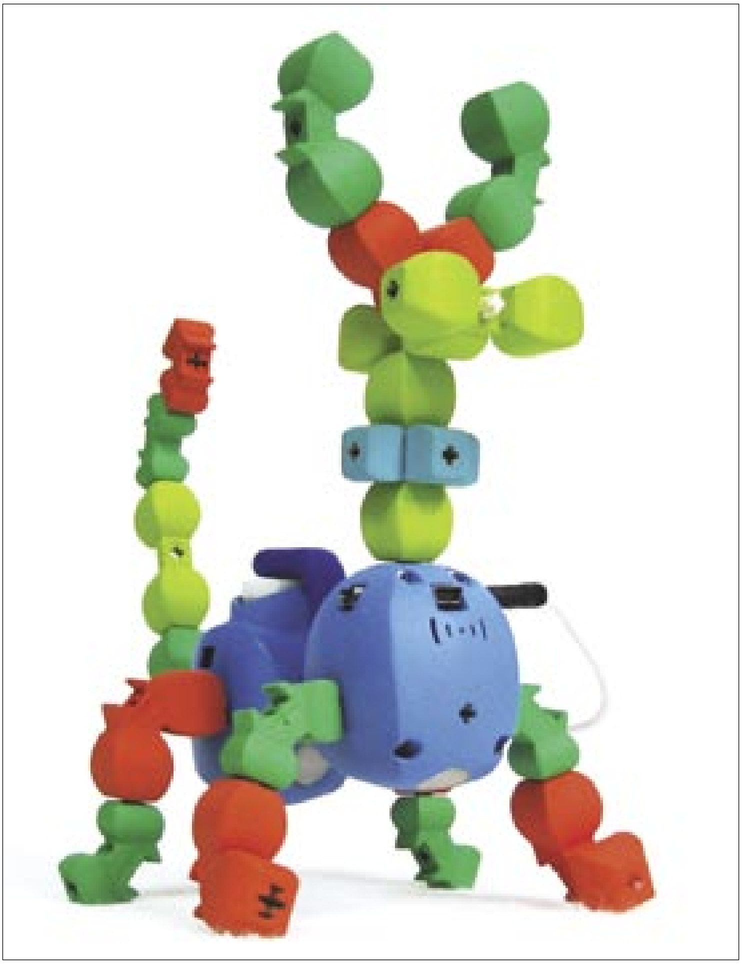


Figure 18
The Topobo building toy with "kinetic memory" that allows children to sculpt with form and motion. Topobo is a scalable, modular, actuated system with which other people design objects, and thus shares conceptual "material qualities" with SCS. Photo: Hayes Raffle, © 2003 Hayes Raffle.

One might imagine a teddy bear clothed in SCS (Figures 19 and 20) that has textural memory, and can replay a child's gesture on its body with a sort of physical "echo" or reflection of the child's motion. When a child rubs the bear, it can later mimic the movement of its fur, acknowledging to the child that the child rubbed it. Through repetition, the child may embody specific gestures with meaning and emotion. For instance, if the child rubs the bear's stomach every time he hugs it, the bear might learn to wiggle its own tummy when it "wants" a hug. Integrating computation into soft stuffed toys, which are both tangible and part of the child's early environment, can support a more familiar, less intimidating, and more emotionally engaging atmosphere for children than other types of computerized interfaces (Cassell and Ryokai 2001: 209).

Figures 19 and 20
SCS could someday be wrapped around children's toys to engage emotions and support learning. Photos and ©: © 2002 Mitchell Joachim, © 2004 James Tichenor.

Digital textiles could also enable cloth to assume the role of display and interface in interactive toys, allowing plush toys to be "interactive" without today's typical flashing lights and recorded voice clips that line toy-store aisles. For example, a plush teddy bear covered with SCS might wiggle its ears and draw a circle on its tummy in response to a child's careful attention. The bear could use cilia movements and sound to convey excitement or happiness in response to a toddler. Different behaviors from the child could elicit different tactile and audible responses from the teddy bear, encouraging the child to care for the bear. The value of such stimulus/response models in toys is evident in the success of products such as Furby™. However, toys like Furby often have limited physical interactions (e.g. vibrating), constraining the depth to which they can use tactile interactions to engage a child's emotions and encourage learning. Combining more sophisticated stimulus/response models with a tactile/kinesthetic interactive material like SCS could facilitate more educational computational toys that are truly "things-to-think-with" (Resnick *et al*. 1998: 282).

While SCS is not yet a thin, flexible, and affordable fabric that toy designers could wrap around a child's plush bear, computational textiles are advancing quickly and SCS offers an opportunity to consider how interactive textiles can support children's growth and learning. On one hand, there is a need to bridge digital interactivity with physical educational manipulatives. Textural interfaces can engage children's bodily-kinesthetic intelligences in interactive experiences, allowing children's physical engagement with material to reinforce cognitive development and learning experiences. On another hand, toys that flash lights and sound sirens to delight a child's senses are increasingly filling toy-store aisles. Such toys are certainly "sensory," but an actuated textile can facilitate a more organic, subtle, and creature-like interface than a siren or flashing light. It may be these subtle, organic qualities of textural materials that help children form the personal, emotional connections that make objects an important part of development.

Touch, Material and Communication

We developed SCS, in part, to investigate how the physical qualities of material could be used to improve remote interpersonal communication (Raffle *et al*. 2003: 529). Communication is fundamentally a multi-modal experience, and touch is an important aspect of human interpersonal communication. Whether a pat on the back, a handshake or an intimate hug, touch conveys meaning and emotion that most communication technology struggles to transmit.

The Tangible Media Group has developed several devices over the past decade that have explored the extent to which shared physical objects can use technology to make remote communication more emotionally intimate and expressive. An early project called inTouch creates the illusion that two people, separated by a distance, can physically interact with the same physical object (Brave *et al*. 1998; Chang *et al*. 2002). The two connected objects, each made of three wooden cylindrical rollers mounted on a base (Figure 21), are connected over the Internet. When one of the rollers is rotated, the corresponding roller on the remote object rotates in the same way.

Figure 21
inTouch allows two people who are separated by a distance to "share" a physical object. © 1998 MIT Media Lab. Photo: © 1998 MIT Media Lab.

A person using inTouch does not perceive a simulation of the other person, but is aware of the device itself. The richness of the interaction comes from the representation of movement as mediated by the coupled objects. This is interesting in that it places great importance on the physical design of the device (Brave *et al*. 1998: 172). inTouch demonstrated that an abstract tactile interface can allow a broad emotional range of expression since the device itself will not dictate a certain interpretation of its movements.

Our prototype SCS design described two picture-framed, electronically coupled SCS devices that could sit on a table top or hang on a wall like a painting. For instance, I might have one device in my living room and my sister may have a coupled device in her living room. When we talk on the phone I might draw gestures on my device that she can see and feel on hers (Figure 22). We might collaborate to draw gestural images, beat a musical rhythm back and forth, or casually respond to each others' movements of the cilia (Chang *et al*. 2001: 313).

Figure 22
SCS uses texture to allow remote interpersonal communication to engage sight and touch. A gesture can be seen, or an image can be felt. Photo: Hayes Raffle, © 2004 Hayes Raffle.

If the same device were built to respond to shadows, it could operate as an ambient information interface (Wisneski *et al.* 1998: 22). As I would occasionally see a representation of my sister's shadow as she walks by her device, I would become aware that she is home and active, and I may strike up an active dialogue between us. The subtle, abstract nature of the cilia is less invasive than pictorial representation like a video conference and invites our participation only when our peripheral awareness is engaged and we choose to open a human channel of communication.

A baby's crib blanket might trigger a small SCS in the parents' kitchen to mimic the baby's bodily gestures over the surface of her blanket. As she rolls around in her crib, a parent might notice if she is restless or peaceful, giving the parent a sense of her physical state. Where a common "baby monitor" can remotely tell you something about a child's speech, an actuated textile might tell a parent or loved one something about the baby's body language.

Placed in a working parent's office across town, the same device can hold a different meaning. Textural changes on the remote device allow an awareness of the child's presence and motion on her own blanket. As the parent occasionally notices that baby is in her crib, resting peacefully or rolling around with life, the parent may feel more closely connected to their child (Weinberg *et al.* 1998: 326). Since SCS is a bidirectional interface, we wonder if parents would want to remotely "touch" their child. That is, touching the office display with one's fingers would cause subtle manipulations on the surface of the baby's blanket. This sort of physical telepresence may help the parent and child form stronger emotional connections despite their temporary physical separation.

SCS as a fabric on the back of cell phones allows a different kind of conversation. A typical phone call may interrupt an ongoing vocal conversation between the recipient of the call and a third person. The recipient may not want to answer the phone, however. He may reach in to his pocket and give the cilia a gentle back and forth gesture to signal to the caller, "not now." Such a gesture can happen without disrupting the flow of the ongoing conversation (Chang *et al.* 2002: 315; Figure 23).

Textural interfaces may facilitate more emotionally rich communication in the future. Designers could engage people's interpretation of texture and incorporate more of people's senses into technology-mediated communication, making the communication richer and more memorable. However, scale and context carry added meaning because bidirectional interfaces may or may not be identically designed and may or may not be in identical contextual settings. As we learned from inTouch, these design decisions will affect how communication is perceived and conducted. While this section focused on applications tailored to hand and finger gestures, other applications may address communication involving the whole body or environment.

Figure 23
ComTouch introduced haptic communication to cell phones. SCS could also support tactile cell phone communication. Photo: © 2001 MIT Media Lab.

Architecture

Our design decision to make SCS a scalable material rather then an object supported our goal for the surface to be used on an architectural scale. As an interface changes its scale from object to environment, our perceptions and interactions with this interface change. This shift is analogous to the change from sculpture to architecture, and the development of various interactive surfaces invites a discussion of the changes in our spatial and peripheral understandings of an architectural scale interface.

In 1996 Kas Oosterhuis (1995) published the article "Liquid Architecture" describing the design of a pair of buildings known as the Salt-Water and Fresh-Water Pavilions, respectively designed by his firm Oosterhuis and the architectural firm Nox. These buildings incorporated numerous electronic sensors into their designs to gather information about both interior and exterior changes. This information ranged from the position of the visitors within the pavilions to the tidal flow of the neighboring sea. The incorporation of computer sensing and display technology in the design of the buildings was a touchstone in the architectural discourse of computationally enhanced environments in which the building is loosely defined as an interface. This concept builds upon age-old ideas that a building's envelope or "skin" mediates between a person and his or her environment. In a computationally enhanced environment, the surfaces are mediating not only between interior and exterior but also between the building's physical form and virtual information.

The architecture of the Salt-Water and Fresh-Water Pavilions, with their twisting amorphous forms, are exemplary of the digitally designed architecture of their time. The buildings' electronic interiors border on sensory overload, causing confusion between the tactile information of the buildings' forms and the projected virtual information. While this perceptual confusion can be seen as a goal of the designers, the opportunity to understand the presented virtual information is lost.

In the 1998 article "Ambient Displays: Turning Architectural Space into an Interface between People and Digital Information" (Wisneski *et al.* 1998) the Tangible Media Group helped forge the idea of ambient media as a research area within the field of human–computer interaction. The article discusses a number of ambient displays that use the background environment to give information to individuals. These displays range from pinwheels that spin at different rates depending upon the amount of change in a system to a projection of water ripples on a ceiling that represent the activity of distant relatives. The article also contextualizes the work within cognitive science research of foreground and background information processing.

The authors argue that one of the most effective uses of ambient displays is for "the display of information like natural phenomenon, such as atmospheric, astronomical, or geographical events"(Wisneski *et al*. 1998: 30). This is remarkably similar to the information that Nox and Oosterhuis chose to display in the interior of their pavilions with differing results. The restraint and specificity of the work of the Tangible Media Group contrasts sharply with the wild exuberance seen in the architectural designs of Kas Oosterhuis and his contemporaries. The ambient displays from the Tangible Media Group (and in much of the work of the human–computer interaction community) are informed by an engineering approach, that is with a clear set of goals and constraints. And thus many of the ambient displays do not seem integrated into the design of the environment, but remain as objects or projections onto it.

A digitally enhanced material such as SCS suggests solutions to problems within both of these approaches. As a surfacing material rather than an object or projection, SCS becomes an integral part of an environment. Incorporated into the design of its environment, it creates an experience where information can move seamlessly from background to foreground. By thinking of SCS as a surfacing material rather than as a display, we can draw from the rich history of interior surface design.

SCS could capitalize on traditional techniques of wallpaper design that mediate the difference between foreground and background information. That is, when we view wallpaper with a complex, repeating pattern, at some moments we tend to view the wallpaper as a field of background information, while at other times we focus on individual details with the foreground of our perception. In the same way, SCS as an interior wall surface could display fields of information that would be perceived either as background or as more detailed foreground information. Its main perceptual distinction (compared to wallpaper) would be its dynamic qualities. Decorative art such as wallpaper is not designed to be the single focus of attention: "[with] a painting," (or video screen, or projection), "even if we fail to see what the exact information on the picture or display is, we are aware that it is meant to be read as such" (Gombrich 1979: 116). The dynamic abilities of SCS would create sufficiently abstract "images" that, unlike a television or projection, the information could move to the background of our perception.

The interplay between foreground and ambient attention can be compared to a balance between pattern and image in which the visual imagery oscillates between representation and pure form. This oscillation is analogous to the confusion between the virtual and physical in the Salt-Water and Fresh-Water Pavilions. The use of pattern and repetition allows multiple readings (or layers of information) to exist at different scales. "Redundancy tends to drain individual elements of much of its meaning and character" (Gombrich 1979: 150), allowing differing patterns or elements within a field to form the focus of attention.

SCS naturally creates a static field of pattern with its repeating array of cilia. A grouping of cilia on SCS can carry semi-detailed information by dynamically generating a unit of pattern across its surface. These units create readings of both the surface itself (that is, the space), and of a more ambient reading of information. "Image" or foreground information then arises from disruptions or disturbances to this repeated pattern that are formed by contrasting movements or even static cilia. Where visual information in the Salt-Water and Fresh-Water pavilions was so overwhelming that it was perceived as texture rather than information, layering information within an intentional pattern could convey large-scale information as multiple layers of meaning that do not overwhelm the viewer.

Interior Design

The visual texture of tracks of a vacuum cleaner across shag carpet resonated as an early concept for SCS. As a medium of interaction, the floor plane is enticing because it is spatially connected to maps and human activity, and the floor registers regular tactile input from people's movement.

As a carpet, SCS might record or replay footsteps over its surface (Figure 24). Like inTouch, one could imagine two linked floors allowing an inhabitant to see the movement of people on the remote floor miles away. Such a carpet redefines the architecture around it as conflicted rooms become tactilely linked: mismatched floor plans would be revealed as ghostly footprints walk across the floor and disappear into a wall as a record of remote passers-by walking across a larger space.

Figure 24
An SCS carpet could display remote footsteps in a friend's room. Alternately, SCS could produce a live weather map of wind over the US; lying on the floor, the motion of the jet stream would gain new meaning as the turbulent wind gives a calming massage. Photo: James Tichenor, © 2004 James Tichenor.

SCS in a public space could compress time and, in a matter of minutes, replay days or months of people's movements. Patterns of ebb and flow would appear as the surface creates a full-scale visual and tactile experience (*Koyaanisqatsi* 1982).

Presenting large-scale dynamic phenomena such as the weather pattern of the United States, SCS reduces the scale of motion from kilometers to millimeters. As an information display, forecasts could be communicated in a subtle and continuous manner. While lying on the floor, the motion of the jet stream would gain new meaning as the turbulent wind gives a calming massage.

Exterior Facade

While investigating sensing methods with our prototype, we found that movements of the cilia generate electrical power in the Actuated Workbench. Although we were investigating sensing techniques, we realized we could store this power for later use. We imagined SCS as an exterior skin on skyscrapers that could both visualize information as a billboard size display and harness energy of the wind forces that blow over the building's facade (Figure 25).

The idea that an alternative energy source can be a visually engaging material rather than a highly engineered object could increase the market for alternative energy. Rather than relying on a moralistic desire to tread less heavily on the earth, an SCS alternative energy facade would also be appealing for its strong visual character. The facade would take wind energy

Figure 25
SCS is imagined as an exterior sheathing for skyscrapers that can harness urban wind energy or display billboard-size imagery. Photo: James Tichenor, © 2004 James Tichenor.

as its input and use pictorial output to reflect current fashions or display advertising. This model challenges the traditional function of a building's skin as a barrier to protect people from the forces of their environment, and presents the architectural skin as a membrane that can transform the forces of nature into the energy required to support the building's inhabitants and the artificial nature of its interior.

As provocative as these ideas may be, further investigation showed that they are not viable with our current prototype. But continuing research and development may allow for a surface that can harness the physical motions of the environment, turning the building into an active part of its ecosystem.

Conclusion

Scale shifts from microscopic biological cilia to body-scale cilia informed our conception for SCS, and we have imagined the material at multiple scales to explore the many possibilities that may be afforded by actuated textiles. Our prototype development was both rewarding and humbling; reflecting upon the aesthetic possibilities and technical opportunities of our models has allowed us to explore more fully applications for tactile surfaces. However, much more work remains to be done. While our current prototype functions well as a planar display, curved surfaces are currently difficult to cover. We are investigating a different approach in which individual "hair follicles" could be inserted onto a curved surface (such as a teddy bear) like pins in a pincushion. Such investigations raise new technical and aesthetic considerations.

The development of electronic skins and fabrics is proceeding quickly, and a textural interface may be achievable in the near future. By drawing on previous work in tangible interfaces, architectural design and interior surface design, we believe that important application domains will include supporting intimate communication, enhancing young children's education and creating informative and aesthetically engaging interactive environments. Throughout our design processes we have referred to the rich history of textile and surface design to guide our conceptual applications for SCS. Unlike other display technologies, textiles have the capacity to engage both sight and touch to convey information. In the future, they may also be able to engage these senses to collect information. We hope that our investigations have inspired the reader to imagine future materials that harness some of the benefits of computer technology while maintaining the benefits of traditional textiles. The absence of interesting textures in many of today's technological devices may be due to the absence of a textural interface, and we are looking forward to a future when designers can literally weave interactivity into the fabric of our environments.

Filmography

Koyaanisqatsi. 1982. Directed and written by Godfrey Reggio.

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