Super *Cilia* Skin: An Interactive Membrane

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ABSTRACT
In this paper we introduce Super Cilia Skin, a multi-modal interactive membrane. We conceived Super Cilia Skin as a computationally enhanced membrane coupling tactile-kinesthetic input with tactile and visual output. We present the design of our prototype, an array of individual actuators (cilia) that use changes in orientation to display images or physical gestures. We discuss ongoing research to develop tactile input capabilities and we present examples of how it can enrich interpersonal communication and children's learning.

KEYWORDS
Tangible Interface, Kinesthesia, Haptics, Interpersonal Communication, Toys, Education, Actuation

INTRODUCTION
Super Cilia Skin is a tactile and visual system inspired by the beauty of grass blowing in the wind. It consists of an array of computer-controlled actuators (cilia) that are anchored to an elastic membrane. These actuators represent information by changing their physical orientation. Our current prototype of Super Cilia Skin functions as an output device capable of visual and tactile expression.

Most existing computational tools rely on visual output devices. While such devices are invaluable, influential studies in neurophysiology have shown that physical experience creates especially strong neural pathways in the brain. When people participate in tactile/kinesthetic activity, the two hemispheres of the brain are simultaneously engaged. This type of learning experience helps assure that new information will be retained in long-term memory [2].

Super Cilia Skin is essentially a tactile and visual system. Its ability to replay dynamic gesture over time and to communicate remote gesture makes it a potentially valuable tool for education and haptic communication. We envision Super Cilia Skin as an I/O membrane with a variety of applications in education and haptic communication.

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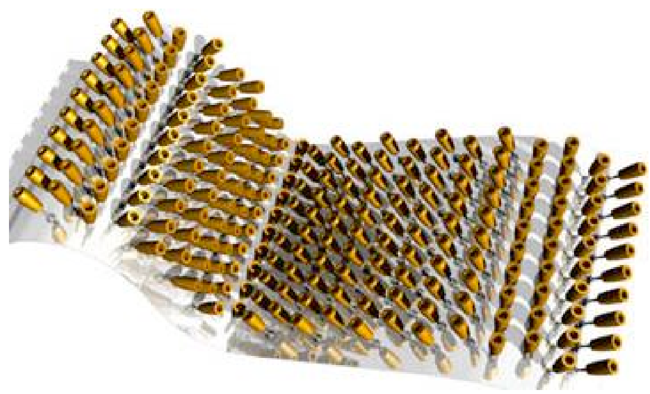

Figure 1. Super Cilia Skin conceptual sketch

OBJECTIVES
Much research in tangible interfaces has sought to employ haptics for interpersonal communication. For example, inTouch uses physical movement of wooden rollers for remote emotional communication [1]. inTouch is successful largely because the interface allows users to ascribe meaning to their partner's physical gestures. Like inTouch, Super Cilia Skin allows expression via a generalized, aspecific interface. However, we feel that Super Cilia Skin can improve interpersonal haptic communication because it is multi-modal; gesture can be seen, or an image can be felt. Users can choose how to engage the different modes of communication. Users can draw pictures for one another, beat musical rhythms, or send subtle physical gestures. As a flexible membrane, Super Cilia Skin can be applied to a variety of designs that are tailored to accentuate particular aspects of these multiple modes of communication.

We also envision Super Cilia Skin as an educational tool. Resnick argues that computation, coupled with tactile/kinesthetic play, can empower children through well designed toys - "digital manipulatives" - that use computation to reinforce education [4]. However, he offers no techniques to directly integrate tactile/kinesthetic interactions with computational models. We propose Super Cilia Skin as a material that could enrich the learning

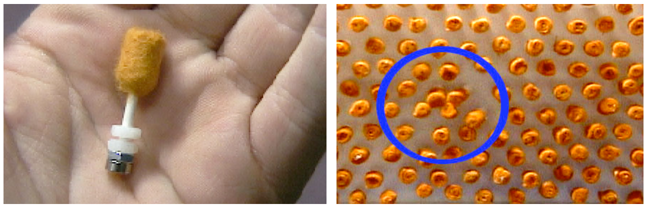

Figure 2. (a) A single cilium actuator and **(b)** cilia displacements due to a magnetic force below the surface.

process by integrating the power of computation with tactile/kinesthetic interactions.

The value of stimulus/response models in toys is evident in the success of products like Furby™. However, these toys have limited physical interactions (e.g. vibrating), constraining the depth to which they can use tactile interactions to enhance learning. Super Cilia skin has the potential to create a rich gestural language that can convey a range of physical responses to engage learning. For example, a Super Cilia teddy bear could use cilia movements and sound to convey excitement or happiness in response to a toddler. Different behaviors from the child would elicit different tactile and audible responses from the teddy bear, encouraging the child to care for the bear. As the child developed, tactile/kinesthetic interactions could remain cognitively relevant to the child's learning level. Resnick praises the value of kinesthetic stimulation in learning toys, and we believe that Super Cilia Skin, with its integration of computation and tactile/kinesthetic interactions, would facilitate his goal of designing digital manipulatives that are "things-to-think-with."

SYSTEM DESCRIPTION AND DESIGN

An array of actuators oscillate in response to a magnetic force. Each actuator is a felt tipped rod with a magnet at its base (figure 2a). The rods are anchored to a silicone membrane with two plastic nuts. A magnetic force below the surface of Super Cilia Skin causes a deformation of the angles of the actuators on the upper surface.

The elasticity of the membrane allows a periodic motion in the actuators. After deformation, the actuators oscillate back to their original position. Furthermore, the elastic membrane allows the cilia to have consistent function independent of gravity. This allows Super Cilia Skin to be applied to various planar or non-planar objects, from a black board to a teddy bear.

We chose cotton felt for the tips of the rods for its tactile and visual appeal. The felt was rolled into a cylinder at the top of the rod so that the upper surfaces of the arrayed rods would visually approximate a contiguous deformable surface.

Our prototype of Super Cilia Skin was designed to be operated by the Actuated Workbench [3]. The Actuated Workbench uses a computer to dynamically control an array of 128 electromagnets, changing their duty cycle to smoothly move magnetic objects on its surface. These magnetic forces can also be used to attract and repel the magnets at the base of each cilium (Figure 2b). Gestural input with a mouse or track ball can be simultaneously conveyed as dynamic movements of the cilia. Patterns or images drawn on the computer, such as geometric shapes or wind flow records, can be visualized or tactilely sensed as oscillations of individual cilia. Very subtle deformations of the cilia are easy to see or feel because humans have an acute ability to identify moving objects.

FUTURE WORK AND CONCLUSIONS

We have yet to perform formal user studies with the interface, but initial observations were encouraging. People easily visually identified geometric patterns displayed in the cilia. While these patterns could not be recognized tactilely, people enjoyed putting the interface next to their faces and some reported with pleasure that the tactile sensations felt like "butterfly kisses." Most people expressed excitement at the possibility of using the prototype as an input device for communication.

With our current prototype we have tested Super Cilia Skin as an output device only. We plan to develop Super Cilia Skin as a stand-alone input/output interface. Preliminary tests suggest that sensing movement across the surface of the cilia will be technologically feasible. Users' movements of the cilia induce electrical currents in the electromagnets of the Actuated Workbench. We believe that these currents could be used to determine position and amplitude of user's input gestures. Once sensing is implemented, we plan to create and test a simple gestural communication tool and evaluate it as a learning aid. We believe that Super Cilia Skin's ability to respond to stimuli with multi-modal behaviors will broaden the breadth of haptic/visual interpersonal communication, and that its ability to integrate computation with kinesthetic and visual feedback will enhance children's learning.

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