Surflex: A Programmable Surface for the Design of Tangible Interfaces

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Abstract
In this paper we describe *Surflex*, a programmable surface for the design and visualization of physical forms. *Surflex* combines the physical properties of shape-memory alloy and foam to create a surface that can be electronically controlled to deform and gain new shapes. We describe implementation details, the possibilities enabled by the use of smart materials and *soft mechanics* in human computer interaction, as well as future applications for this technology.

Keywords
Smart materials, shape-memory alloy, actuated surfaces, 3D modeling, tangible media.

ACM Classification Keywords
H.5.2 [Information Interface]: User Interface — Haptic I/O

Introduction
Designers and engineers have always struggled to ease the transition between their ideation and fabrication processes. With the advent of personal computers, a great deal of this effort has focused on overcoming the idiosyncrasies imposed by digital tools when bridging the gap between virtual models and the material limitations of the physical world [6].

figure 1. Surflex's surface deformation in three steps

Today, there is an increasing number of haptic and tangible interfaces for modeling and manipulating virtual constructions. However, the reverse process – virtual tools that manipulate physical objects – has proven to be a greater technological challenge [7].

In order to address some of these issues, we are developing *Surflex* (see figure 1), a programmable surface that can take new shapes by combining *active* and *passive* shape-memory materials.

Previous Work

The paradigm of ubiquitous computing has for some time strived to blur the boundaries between computation and materiality. While digital information can be copied, deleted and transformed innumerable times without decay or expense, designers and researchers are faced with the electromechanical constraints of kinetic systems and finite physical resources which break and wear over time. For instance, 3D printing is a process that allows for the fabrication of almost any object at high resolutions; however, it is not reversible to accommodate revisions and, more importantly, physical changes in a printed model cannot affect its virtual correlate.

To address this issue, researchers have sought to design three dimensional and kinetic displays that can serve as better interfaces for manipulating and visualizing digital information. One example is *Lumen* [8], a kinetic display consisting of plastic rods embedded with LEDs, which can be raised and lowered to display kinetic and visual images. Another example is *Aegis Hyposurface* [5], a wall-sized structure constructed out of interconnected metallic plates and actuated by an array of pneumatic pistons. In spite of the visually striking effect they create, these technologies are limited by the fact that they mimic surface deformations with an array of linear actuators, rather then embedding the actuation into the surface itself. This choice makes it impossible for the surface to be wrapped around objects and bodies, since it is tethered and constrained to a bigger structure, which limits the range of shapes and angles of curvature it can create.

The *Surflex* architecture is unique in that it combines the physical properties of its materials to generate kinesis. Moreover, being programmable and reversible, it creates an interface for manipulating surfaces with the same fluidity we have when designing virtual objects and spaces. *Surflex* is a step towards building a direct link from the digital to the physical world and back, without giving away computation precepts in exchange for physical affordances [4].

Soft Mechanics

One of the most interesting characteristics of smart materials is their potential to overcome the physical limitations imposed by current kinetic systems [1]. *Simple machines,* such as the pulley, the inclined plane or the wheel, were devised to be primarily constructed from materials such as wood or steel, where material rigidity and strength are desirable qualities [9]; however, these restrictions are no longer relevant when we consider designs that are based on smart materials. Shape-memory alloys and polymers allow machines to be built out of malleable components, driving their actuation from changes between different memory states and elasticity.

In our research, we are looking at how these *soft mechanisms* can be electronically controlled and combined into more elaborate assemblies, specifically looking at user interaction and the ubiquitous communication applications they enable. We use the term *soft mechanics* to refer to systems based on smart materials that generate kinesis via transitions through different memory and elasticity states. *Soft mechanics* is a powerful design approach, opening up novel possibilities for the construction of biomimetic robots [10] that can be squeezed flat to reach inaccessible places and then regain their shape, or for adaptive furniture or wearables where softness and malleability are more appropriate affordances for human interaction [2].

Surflex: A Programmable Surface

Surflex is constructed from 1” foam which can return to its original shape after being compressed. This substrate is pierced by 4 assemblies of 2 printed circuit boards (PCB) each, which are connected to each other through 8 shape-memory alloy coils arranged on an x,y grid. A shape-memory alloy (SMA) is an alloy made of nickel and titanium that, once treated to acquire a specific shape, has the ability to indefinitely remember its geometry. After undergoing a physical deformation, an SMA wire can be heated to its final transformation temperature (A_f) and regain its original shape [3].

Surflex works by counteracting the contraction force of the SMA strands with the ability of the foam to return to its original shape. Through resistive heating, it is possible to electronically control the temperature of the SMA coils to make them contract. Since the boards on both sides of the foam are attached to each other, they cannot move in relation to the foam, and the contraction of the SMA coils cause the surface to deform (see figure 2).

Combining horizontal (x) and vertical (y) compressions, it is possible to bend the foam composite into any shape in the z-plane. When the SMA cools down to ambient temperature and reaches its ‘malleable’ martensite (M_f) state, the foam becomes stronger than the SMA and forces the composite back to the foam's 'memorized' state.

This surface deformation architecture can also be applied to materials other than foam, dramatically increasing the range of materials properties, textures and surface qualities from which we can build tangible interfaces.

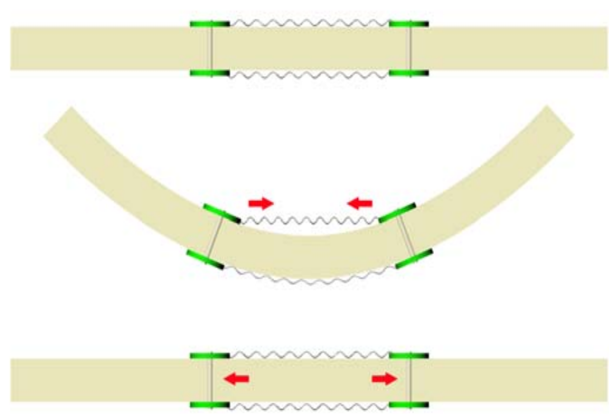

figure 2. Deformation process: (Top) *Surflex* at its initial state when the SMA coils are malleable and the foam gives *Surflex* its shape; (Center) Upper SMA coil contracts through resistive heating, pulling the PCB assemblies together and curving the surface; (Bottom) After the SMA coil is unpowered and cools down, it becomes malleable again and the foam pushes it back to its original shape.

Soft Pixels

In our prototype, we have implemented an array of 8 SMA coils which can generate an unlimited number of surface deformations from 256 combinations of actuation. Their arrangement suggests a new pixel format, where the display unit is described by the amount of deformation it can cause on a surface, rather than by the wavelength, luminosity and viewing angle of the individual pixel. In the case of *Surflex*, every 'pixel' is composed of two horizontal and vertical SMA coils on each side of the foam, totaling four strands, and its display range is a measure of the angle of bend of the substrate – from 0 to 360 degrees in both x and y planes (see figure 3). For instance, by combining small angular bends of sequential pixels, *Surflex* could create a curve with a large radius, while a series of sharper bends could cause the surface to wrap around itself.

Shape and Accuracy Limitations

Resolution for this kind of display can be measured as the amount of deformation per surface area that it can generate. In this case, *Surflex* has 2 soft pixels per 4 square feet. Soft pixel displays with high resolution could be used for modeling small objects, such as cell phone or a chair, while low resolution ones could be used for large scale architectural models where details are not a requirement.

Another important factor which cannot be ignored is the role played by gravity in this design. If *Surflex* were to be hung on a wall, the top SMA strands would have to be strong enough to lift the whole structure, while strands at the bottom would only have to account for the weight of the lower part of the structure. Increasing the actuation force of the SMA would solve this problem, but would also increase the power requirements or frequency of heating cycles.

Finally, due to its topological configuration, *Surflex* is limited to homeomorphic shape changes and could not be used to create perforated or separate structures, being restricted to shapes which can only be achieved through the deformation of a single surface.

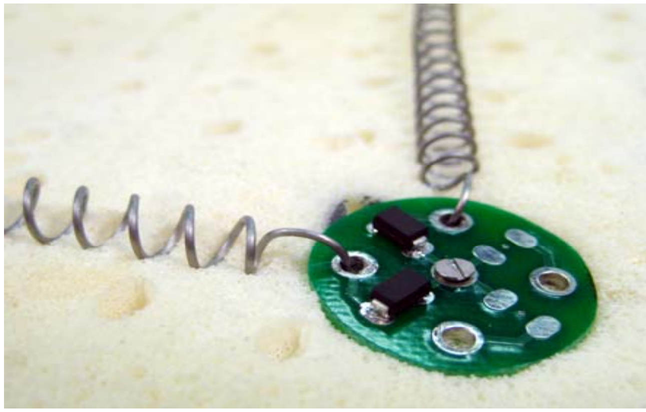

figure 3. Detail of circuit board and SMA coils

Power and Control

To deliver power to each one of the SMA strands, our design uses a multiplexing grid embedded in the foam and diodes placed on the PCB nodes to prevent the SMA grid from acting as a resistor network. This approach reduces the complexity of the connecting nodes, but increases the amount of connections between the controller circuit and the surface nodes.

Another approach for the construction of *Surflex* that we plan to explore is the use of 'smart' power distribution nodes that can communicate with each other wirelessly or through the SMA. This would require a sandwich of foam, power and ground electrodes, and nodes outfitted with a microcontroller, current controllers and radio communication. This set-up simplifies the power distribution considerably, but the bigger nodes would limit the surface's miniaturization.

Application Scenarios

We currently envision two main applications for this technology: the real-time computer modeling of objects and spaces, and the construction of adaptable interfaces.

Tabletop and Architectural Modeling

As an alternative to subtractive or additive 3D rapid fabrication processes, *Surflex* can be used as a tool for displaying computational models in real time. Designers could make their models in a CAD program and have that design instantly printed to a tabletop *Surflex*, which could reconfigure itself to represent any curve or shape, at different scales and degrees of resolution. Another possibility is modeling at a room-size scale, where a large *Surflex* could be hung as walls in a room and quickly updated to reflect different space arrangements or acoustic profiles.

Adaptable Interfaces

One application domain for programmable surfaces that we are investigating is the design of physical interfaces that can change shape to accommodate different uses and contexts. By looking at body language, gestures and our human interactions, objects and spaces can learn to adapt to their different conditions of use and respond with *just-in-time affordances*, ultimately supporting more relevant interactions which could not have been predicted by their original designers. This shift has a dramatic impact on how designers understand and use computers in embedded systems. Rather than sifting through an array of sensors, actuators and embedded computers that can execute a certain programmatic control, the design choices lie in picking the right computational metaphors and parametric delineation which physically describe and encode an object's intelligence in its materials and mechanics.

Conclusion and Future Work

In this paper we have described *Surflex,* a fledging research effort directed towards the design of programmable surfaces and structures which use the physical properties of materials to generate actuation. In the future we plan to increase *Surflex*'s resolution as well as experiment with alternative power distribution and control methodologies, specifically looking at how different materials can provide unique affordances and interaction possibilities for *soft mechanics*.

The effectiveness and impact of programmable surfaces will be largely determined by the development of fast and energy efficient shape changing materials that can look, feel and behave more like the materials we use on a daily basis. While our research goal is to create the tools for designers to seamlessly embed computation into the environment and its materials, we believe that *Surflex* also raises important questions: Once objects and spaces become kinetically reconfigurable, how can we control and design their affordances? Moreover, how can computation precepts determine their form, behavior and interaction metaphors?

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