Smart Material Interfaces: A New Form of Physical Interaction

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Abstract

Smart Material Interface (SMI) is the latest generation of user interface that makes use of engineered materials and leverages their special properties. SMIs are capable of changing their physical properties such as shape, size and color, and can be controlled under certain (external) conditions. We provide an example of such an SMI in the form of a prototype of a vacuum cleaner. The prototype uses schematic electrochromic polymer at the suction nozzle of the vacuum cleaner, which changes its color depending on the dust level on a floor. We emphasize on the new affordances and communication language supported by SMIs, which challenges the current metaphors of user interfaces in the field of HCI.

Keywords

Ubiquitous Computing; Smart Materials; Arduino.

ACM Classification Keywords

H.5.m [Information interfaces and presentation (e.g., HCI)]: Miscellaneous

Introduction

Advances in material and Nano sciences have made it possible to develop smart materials that possess one or more properties that can be changed or controlled by external stimuli such as stress, moisture, temperature, pH, electric or magnetic fields. Smart materials are defined as 'highly engineered materials that respond intelligently to their environment' [1]. Some examples of smart materials are electroactive polymers, phase change materials, chromogenic materials, smart fluids, and self-healing materials [1, 11].

Smart Material Interfaces (SMIs) are the latest generation of physical user interfaces that utilizes engineered 'smart materials'. The central focus of SMIs is to enrich the output modality by allowing changes in the physical and material properties of user interfaces [8]. The current physical interfaces such as tangible, haptic, table-top, organic, augmented, and exertion interfaces have very limited scope in their output mechanisms to allow material and physical changes. Referring to his work on Tangible User Interfaces (TUIs), Ishii [5] commented: *"Although the tangible representation allows the physical embodiment to be directly coupled to digital information, it has limited ability to represent change in many material or physical properties."* SMIs propose using materials that have inherent or 'self-augmented' capabilities of changing physical properties such as color, shape and texture, under the control of some external stimulus such as electricity, magnetism, light, pressure and temperature.

- **Immediacy** – they respond in real-time.
- **Transiency** – they respond to more than one environmental state.
- **Self-actuation** – intelligence is internal to rather than external to the 'material'.
- **Selectivity** – their response is discrete and predictable.
- **Directness** – the response is local to the 'activating' event.

Text Box 1. Characteristics of Smart Materials [1].

In this paper, we describe Smart Vacuum Cleaner (SVC) prototype, a work-in-progress example of SMI. SVC uses a schematic electrochromic polymer on its nozzle area, which can change its color when dust is detected on a floor. With the example of SVC, we would like to emphasize the importance of smart materials for supporting new forms of physical interaction.

Related Work

The CHI community has seen a growth in user interfaces that involve smart materials. Coelho and Zigelbaum [3] have developed a set of programmable surfaces, called Surflex, SpeakCup, Sprout I/O, and Shutters utilizing shape changing smart materials. For example, Surflex [4] utilizes physical properties of shape-memory alloy and foam to create a surface that can be electronically controlled to deform and gain new shapes. Move-It [10] is another example that uses shape memory alloys to provide active physical feedback via its paper clips and make note taking on Post-Its more interactive. Organic User Interfaces (OUIs) are non-planar displays that may actively or passively change shape via analog physical inputs [12]. OUIs also emphasize on the multi-faceted and multi-shape displays that take the form of any organic object.

Ritter [11] lays out several examples of smart materials that are able to reversibly change their color and/or optical properties in response to one or more stimuli through the external influence of light, temperature, compression, an electrical or magnetic field.

Smart Materials & User Interfaces

One of the major limitations in the current physical interfaces (e.g. tangible, haptic, organic interfaces) is the lack of material and physical expressiveness in their output modalities [8]. Secondly, the digital display metaphor is quite prevalent in these interfaces (also actuated objects, LEDs and projection techniques), where output is more or less limited to changes on a digital display and in some cases with limited expressiveness via vibrations and a mix of other multimodal support (voice and visuals).

With the use of engineered smart materials, objects can have property change capability, energy exchange capability, and reversibility [1]. Text box 1 shows other characteristics of smart materials. Additionally, smart materials do not require any dedicated sensors or actuators, smart materials inherently possess such properties that are self-sufficient.

Motivations: Why SMI?

First, we believe that there is a need to make the vision of ubicomp, as conceived by Mark Weiser [13], more relevant. We see a trade off in the ways this vision is applied in the current research. The central idea behind the vision of ubicomp is to seamlessly embed computing in the everyday used objects, both socially and procedurally. The material qualities of these everyday objects play a big role in the social and procedural practices of people. In the current ubicomp research, the material and the computation are seen detached from each other. As [3] suggests, electronic components are seldom integrated into objects' intrinsic structure or form. We believe that there is a need to highlight the blurring boundaries between the material qualities of an object and the computational functionalities it is supposed to support.

Second, the technology push from different fields of material sciences has provided new possibilities to integrate materials such as metals, ceramics, polymeric and biomaterials and other composite materials for designing products. A wide range of smart materials can be seen in the literature [1, 11] that can change their shape, size, color and other properties based on external stimuli. These properties of smart materials can be used to create new kind of interaction and interfaces.

Third, with the use of smart materials, as designers, we can introduce a new communication ‘language’ to users. Use of screen-based interfaces has dominated the user interfaces for several years now. They use icons, texts, and other types of widgets to support communication with users. Smart materials can introduce new semantics to human-computer interaction research, which focuses on change of shapes, colors, size or positioning. Of course, the potential and semantic value of such a type of communication has to be explored and experimented further. However, the use of smart materials can be seen as a radical shift in the way we see our user interfaces.


(a) (b)

Figure 1. A sketch of vacuum nozzle with smart material attached on top (a). Our prototype with electrochromic polymer (b).

Smart Vacuum Cleaner (SVC) Prototype

In this paper, we introduce our initial efforts on utilizing smart materials in consumer products. We have conceptualized an intelligent vacuum cleaner that has a smart material attached to its nozzle area which can inform users about the dust level on a floor by changing its color (figure 1). SVC is our work-in-progress prototype that is presented here as a proof of concept. SVC uses schematic electrochromic polymer (attached on top of its suction nozzle) which can automatically change its color from being transparent to blue when it detects dust from a floor. The basic idea here is to guide users in cleaning by the change of color at the nozzle area – which is visible to users when they are using vacuum cleaners.

Our current prototype uses an optical dust sensor, an Arduino microcontroller, an electrochromic polymer and a vacuum nozzle. As it can be seen in figure 2, the dust sensor is attached to Arduino and is programmed to produce a voltage output when dust is measured. Arduino is also connected to the electrochromic polymer which changes its color when it receives voltage from Arduino. The dust sensors have to be inside the nozzle as well so that it can detect the dust.

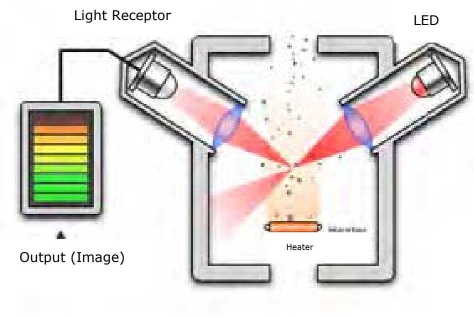


Figure 3. Optical dust sensor principle: Light reflects on the particles passing through the hole and they are picked up by the photodiode which produces a voltage.

For illustration purposes, we have kept the dust sensor outside. The mechanism of this dust sensor can be seen in figure 3.

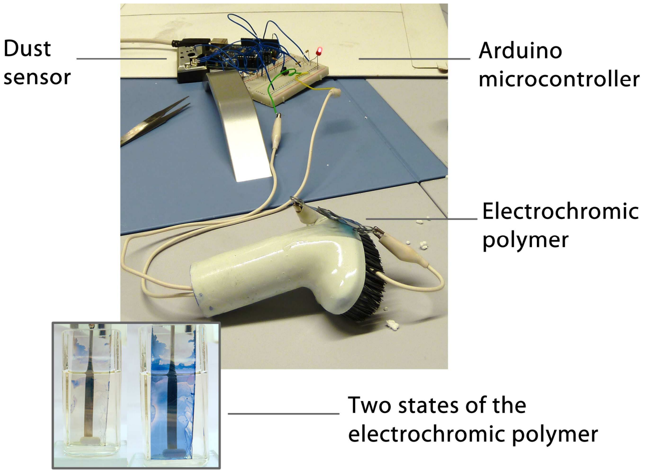


Figure 2. The setup of the SVC prototype: Arduino microcontroller connected to dust sensor and electrochromic polymer.

Electrochromic polymer

Based on the work of Jain et al. [7], we developed a chromogenic system with the help of material science researchers. As it can be seen in figure 4, between two indium tin oxide (ITO)-coated polyethylene terephthalate (PET) surfaces a mixture of polymer was placed. PET is flexible in nature and it can be easily attached to a curvy surface of a vacuum nozzle.

The color changing effect of this system is based on reduction and oxidation of PEDOT:PSS/PAH films, which changes their light transmission and absorption values. To achieve high contrast in electrochromic devices, two polymers are used. A cathodically coloring polymer and an anodically coloring polymer, deposited onto transparent electrodes (in this case, the ITO coated PET), and separated by an electrolyte (the PAMPS gel) to allow ion transport. The anodically coloring polymer appears transmissive in its neutral state. Upon oxidation (the removal of electrons), it colors absorbing light in the visible region. The cathodically coloring polymer is colored in its neutral state, becoming transmissive upon oxidation. When both polymers are combined together in serveral multilayers and a voltage is applied, the device switches between a colored state and a transmissive state [2].

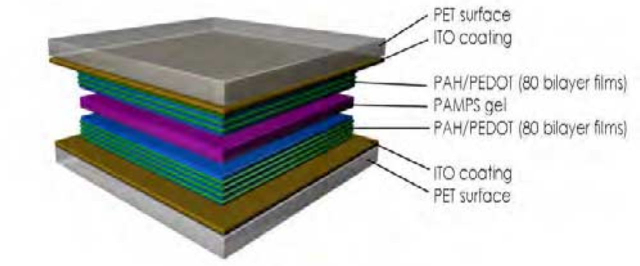


Figure 4. Schematic electrochromic polymer system; two PAH/PEDOT:PSS bilayer films, separated by a conducting polymer gel (PAMPS) between two ITO coated PET surfaces.

Discussion

Based on our initial work on SMIs, we would like to discuss the following issues about the use of smart materials.

1. Form is the interface

The versatile capabilities and variety in their forms (solid or liquid) allow smart materials to be integrated into any type of product. If needed, they can be

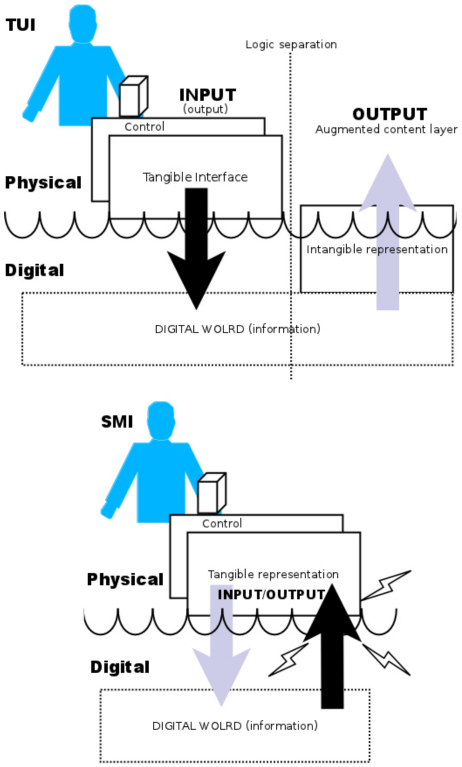


Figure 5. A comparison of TUI and SMI, adapted from [6].

engineered to take form of an actual object. This allows the form of a product to be an actual interface. With the use of smart materials the form will be able to follow users' actions and the form will become the interface which communicates information to users. In this way, SMIs make the form dynamic. SMIs can communicate information by acquiring new forms (by changing color, shape or size) which themselves carry specific communication language.

In this paper, we showed an example of a vacuum cleaner. For the purpose of prototyping, we only used a small portion of smart materials. However, it would be possible to utilize other types of smart materials which can take the shape of the whole nozzle. This allows the form of a product to be an actual interface.

2. Close coupling on Input/Output

SMIs allow close coupling between input and output mechanisms, as they both would be observable through material and physical changes. To make things clearer, we provide a very brief comparison of SMI with Tangible User Interface (TUI) in figure 5. In TUI, when the user interacts with a physical form of information, the object translates movements into commands and data in a digital form for the system. Once the computation has been done an output is prompted to the user with a representation.

With the use of smart materials, SMI attempts to overcome the limitation of TUI. SMI focuses on changing the physical reality around the user as the output of interaction. SMI promotes a much tighter coupling between the information layer and the display by using the tangible interface as the control and display at the same time – embedding the augmented information layer directly inside the physical object. It uses the physicality of the object as a way to deliver information. Utilizing smart materials' properties, SMI can support cohesive interaction by maintaining both channels (input and output) on the same object of interaction. The interaction constructed in this way will grant the user a continuous perception of the object and of the output with a persistent physicality that is coherent with the space.

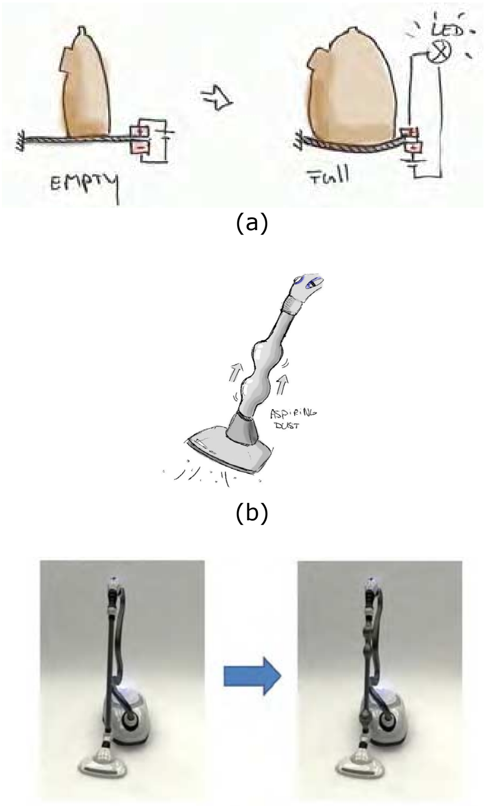
3. Natural interaction & communication

It is natural to observe the effects of a physical action in the physical and material form and not in a digital form. Where TUIs (and other physical interaction techniques) focus on naturally interacting with information focusing on the input modality, SMIs attempt to support natural interaction in both input and output mechanisms. Secondly, SMIs go beyond the display metaphor. As we described earlier, SMIs communicate via its own form, utilizing color, shape, size and energy exchange. It does not need any dedicated displays as such.

In addition, SMIs utilizes a primitive communication language with color, shape and size. This radically shifts the communication paradigm from WIMP to any type of natural behavior a user is capable of.

Conclusion & Future Work

In this paper we described an early prototype of SVC, an example of a fledging research effort directed towards designing user interfaces using smart materials. SMIs do not require displays, with the material being both the interface and input-output stimuli. Their physical characteristics may be enough to carry and convey information to users. We foresee a wide range of applications being developed using smart materials in the near future. In fact, recent literature



(a)

(b)

(c)

Figure 6. Creative ideas for vacuum cleaner, using shape changing smart materials.

shows that smart materials are already used in the domain design and architecture [1], surgery [9] and creative arts [11].

The effectiveness and impact of SMIs will be largely determined by the development of robust and energy efficient smart materials that can behave and feel like the materials we use in our everyday lives. Hence, we need to acknowledge that the development in SMI research is necessarily a multidisciplinary effort. Our current project involved researcher from different disciplines such as computer science, industrial design, material sciences and mechanical engineering.

In addition to using the electrochromic polymers for color changing, we are also thinking about exploring the use of shape-memory alloys to allow physical changes in the shapes and behavior of the vacuum cleaner. Our initial ideas are shown in figure 6. Figure 6a shows the size of the vacuum cleaner increasing, to inform its users that the dust bag in the vacuum cleaner is full. Figure 6b and 6c shows a more playful concept for vacuum cleaners, where the pipe of the vacuum cleaner changes its shape when a relatively large objects are sucked into the vacuum cleaners.

Acknowledgements

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