Smart Material Interfaces as a Methodology for Interaction

A survey of SMIs' state of the art and development

Andrea Minuto
Human Media Interaction Group
University of Twente
PO Box 217, NL-7500 AE Enschede, The Netherlands
a.minuto@twente.nl

Anton Nijholt
Human Media Interaction Group
University of Twente
PO Box 217, NL-7500 AE Enschede, The Netherlands
a.nijholt@utwente.nl

ABSTRACT

In this paper we give an overview of the work done on the methodology of using smart material interfaces as it appears in the literature until now. We address the opportunities offered by smart materials as they have been exploited by other researchers who created smart material interfaces. We do so by surveying smart materials by kind and by looking at how they have been exploited.

Categories and Subject Descriptors

H.5.2 [**Information Interfaces and Presentation**]: User Interfaces - Interaction styles.

Keywords

smart material interfaces, design, prototyping, methodology, survey

1. INTRODUCTION

In the past, several attempts were made to identify and stimulate the production of novel interfaces with physical properties that can be manipulated by the user. It started with the idea of recreating what we already knew in real life: desktop and folders with files. So the idea of WIMP (window, icon, mouse and pointer)[1] was born,. Some years later Mark Weiser proposed the vision of Ubiquitus Computing [30]. Progressively new sub-visions were born such as Tangible User interfaces (TUIs) [7] and Reality-Based Interfaces [8]. Even if in many fields Natural Interactions [5] researchers tried to create a more natural interaction by interpreting gestures and voice commands, in many other subfields the concept of Physical Interface became a persistent idea. What draws the attention in these years is the application of programmable smart materials [18] to create augmented or interactive objects, especially speaking of Organic User interfaces design [25].

[1]Coined by Merzouga Wilberts in 1980, developed at Xerox PARC in 1973.

SMI'13, December 13, 2013, Sydney, Australia

http://dx.doi.org/10.1145/2534688.2534689.

2. SMIs IN SHORT

As said in [13], from this turmoil of ideas about tangible interfaces, materials and users hungry for more physical feedback was born the idea of Smart Material Interface (SMI). Born to provide for the limits of TUIs, SMIs try to engage the user in different ways. SMIs try to create a new channel of communication, based on the properties of the material and the information perceived by the user. In TUIs the interfaces are often made of two distinctive information layers, one of manipulation/input and the second of feedback/display. This second part is usually displayed as an overlay of projected information that have no direct coherence with the modality of interaction (tangible Vs. projection-intangible). They tend to focus more on the input mechanism than on the output. But as Ishii explained in [6] the major limitation of TUIs is the incapability of making changes in the physical and material properties of output modalities.

As described in [13], the basic idea behind the SMIs vision is that it attempts to utilize available engineered (smart) materials as physical properties of an interface to convey information to its users. SMIs attempt to close the gap between the computation and the physical medium, where the physical medium itself is capable of making expressive changes. This way everyday objects can convey information by means of their physical properties. SMIs use the material itself as a medium of physical representation. They put emphasis on the medium used for the interaction, the object itself, instead of having a simulacrum giving the idea of interaction of another object augmented as input system [13].

By making use of these new technologies they created new kinds of interaction, novel interfaces and displays, as well new and unexpected artistic performances. See [13] for a more comprehensive view on SMIs in research field.

3. SMART MATERIALS BY KIND

Smart materials are materials that have one or more physical properties that can be changed in a controlled way by external stimuli, as we can see in this section.

We will briefly show here some of the relevant categories of Smart Materials [1]:

- Materials inducing external visual changes:

- Changing color, transparency (Chromogenic Materials)
  - Electrochromic materials change color or transparency by the application of a voltage (e.g., LCD).
  - Photochromic materials change color in response to light (e.g., sunglasses).
  - Thermochromic materials change in color depending on their temperature (e.g., graphical thermometer).
- Light emitting materials
  - Electroluminescent materials emit light on the application of voltage.
  - Fluorescent and Phosphorescent materials produce visible or invisible light as a result of incident light of shorter wavelength (e.g., fluorescent ink, phosphorescent ink)
- Inducing movement
  - Materials that change shape:
    - Shape-Memory Alloys (SMA) and polymers are materials in which a deformation can be induced and recovered through temperature changes.
    - Magnetostrictive materials change shape under a magnetic field and also change their magnetization under mechanical stress.
    - Ferrofluid is a liquid which becomes strongly magnetized in presence of a magnetic field.
    - Magnetic shape-memory alloys are materials that change their shape in response to a significant change in the magnetic field.
    - Temperature-responsive polymers change upon temperature variation.
    - Photomechanical materials change shape under exposure to light.
  - Dielectric Elastomers (DE) are materials which produce large strains under the influence of an external electric field.
  - Polymer gel or pH-sensitive polymers are materials that change in volume when the pH of the surroundings changes.
  - Piezoelectric materials are materials that when a voltage is applied, will produce stress within the material. Systems made from these materials can be made to bend, expand or contract when a voltage is applied.

- Materials inducing other effects
  - Self-healing materials have the ability to self repair damage.
  - Magnetocaloric materials are compounds that undergo a reversible change in temperature upon exposure to a changing magnetic field.
  - Phase-change materials are capable of storing and releasing large amounts of energy. Heat can be absorbed or released when the material changes state.
- Smart Textiles
  - Smart Textiles are not always smart material by definition, but a special category that we want to include that comprehend a variety of textiles that change colors, self-heal, transmit information or keep information all thanks to smart materials. They are engineered textiles with smart materials inside or a mix of compounds that gives them smart properties even if they are not smart materials at the bases.

The above list is not meant to be a complete list, there are more categories and many new materials are being created from one year to the next. As interaction designers and researchers of computer interfaces, we are especially interested in what we can use directly to create interaction. We want to convey a message with an action, mostly something the user can sense directly, such as: change of shape, change of color or light emission. The only limit is our creativity.

In the following section we present an overview of existing works that make use of part of the above listed materials.

4. A MATTER OF MATTER AND METHOD

Many researchers have applied smart materials by embedding them to create interactive new media for the public. We can spot several articles that focus their attention on creating frameworks or methodologies to engage the user, to make them play or unleash their inner creativity. These frameworks can also aim to support rapid prototyping for the researchers themselves. The following examples show and draw attention to the methodology of application of the materials for creating interactive interfaces. Most of them not only give the idea on how to employ the material but also present a methodology for interaction and for creating new kinds of interfaces, in many cases for stimulating the creativity of the user, for prototyping or for pure entertainment.

We grouped the works in three subsections by the main kind of support used in building the interfaces. Our interest is not only in the way it is done but also which and how the methodologies are used and what the pattern is behind the success of the interface itself. We aim to find out more about how to communicate using the material itself.

4.1 Mainly paper

In '98 Wrensch and Eisenberg [31] started their initial efforts toward integrating computational and crafting media by creating a computationally-enhanced craft item, posing the bases for many future works as we will see in this paragraph. The Programmable Hinge they realized was firstly made with a normal motor actuation, soon after, improvements were made changing geometry and applying an SMA wire. Later on many of them started to use cheaper and common office materials, such as paper or cardboard, for the support material. This is the case for Autogami [32], where the authors present a toolkit for designing automated paper craft. AutoGami has hardware and software components that allow users to create physical animated paper crafts without previous knowledge of electronics. With the help of induction coils, the AutoGami set gives power to the user's creations without power cords or cables. The user can animate his creation as he sees on the screen by applying SMA wires to the back of the paper shapes. Autogami also supports rapid prototyping.

In 2009, Coehlo et al. proposed the idea of pulp based computing [2]. Their aim was to develop an electronic paper composite, which combines traditional paper-making techniques with the interaction possibilities of smart materials. This is done by embedding sensors, electroactive materials and electronics into the paper itself to convey the affordances and tactile qualities of paper, while still keeping the potential of computers computing. Among the most innovative ways of paper-moving with smart materials there is the Animated Paper for building toys of Koizumi et al. [10]. By using SMA helix wire heated with lasers, Animated Paper represents another step to a wireless prototyping platform which combines paper, SMA, retro-reflective material and copper foil. They created flapping origami cranes and walking paper pandas, but because of safety measures, caused by the employment of a high energy laser, all the interaction needs to be made a-synchronically in a box, and it does not allow direct interaction. They also created an interesting flower garden that blooms when heated from concentrated sunlight (by holding a magnifying lens close to the flower). This represents an interesting real life application and provides a low-cost and eco-friendly platform for the user to develop and test new models.

In contrast to the expensive design set from the previous example, Greg Saul's Interactive Paper Devices are extremely cheap [24]. He describes a family of interactive devices made of paper and simple electronics such as paper robots, paper speakers and lamps. He developed software and construction techniques for supporting a do-it-yourself (DIY) process and a low-cost production. His robot "sleepy box" uses nitinol for creating movements, it sleeps making its head nod slowly and it reacts instantly to noise or dance, making the head jump up and down. Saul describes a methodology to create contacts and interactive movable elements using magnets and copper tape.

Qi and Buechley further develop the concept of paper based computing through an interactive pop-up book [21]. They create and report the techniques for its development hoping to provide a reference for whoever would like to follow their steps. They use a mix of materials like piezo resistive elastomers, resistive paints, and shape memory alloys to build the pop-up book. By embedding components and SMA on the pages they create an intriguing combination of material experimentation, artistic design and engineering. They also show that function and aesthetics can be tightly coupled. After this experience they continued their research by organizing workshops and testing the newly acquired knowledge about how to use SMA with paper [22], sharing information through both articles and online resources (for example with the crane tutorial [20]). With the "untoolkit" we can learn more on how to "frame the technology for the target audience" [11], how it is important to adapt the complex materials, such as micro-controllers, conductive inks and smart materials and the contexts in which they are embedded. It shows the tight integration of craft and technology using both micro-controllers and paper. In Paper mechanisms for sonic interaction [4] we can also see mechanics for creating pop-ups with conductive ink to augment paper and creating sensors for controlling paper interfaces, similar to Qi's work but more oriented to producing sounds and effects. One last example for this part is [9] a recent experiment applying the techniques from above (with paper, controllers and conductive inks, mostly by using capacitive touch) with children to stimulate creative expression and storytelling. In the article the authors point out some interesting issues about how the children used the materials and how this some times caused problems on the final interface effectiveness. The participants in some cases created a "holistic combination of functional and aesthetic affordances that fit their specific needs" using the material as the medium both for expressing the functional desire and for fulfilling his aesthetic side.

4.2 Textiles and soft materials

Creativity can also be unleashed without paper: this could be by using textiles or by making wearable interactive objects. This is exactly what Perner-Wilson does by creating the Kit-of-No-Parts [19]. She explores the concept of handcrafted electronics using mainly e-textiles. She created a related site called "how to get what you want" [23] and over the years continued documenting all her activities and all her research, publishing step by step tutorials, materials reviews, videos and suggestion for anyone interested. She follows a DIY approach, with elegance and knowledge, experimenting and posting results. She has organized several workshops trying to convey a style of working that emphasize a creative use of (smart) materials. She describe how craft materials support a more understandable approach to creating technology and that the results of this process can be more transparent and expressive. A similar idea for managing nitinol wires can be found in [12]. It is a tutorial-oriented technical paper, which shows the design history and the prototypes of Follow the Grass, a smart material interactive display shaped like blades of grass. It is rich of information on how to solve problems with the nitinol wires and all the lessons learned through the mistakes made by the researcher. The SMAs here are the main motor that drives the motion of the blades of grass.

Surflex [3] is a programmable soft surface for the design and visualization of physical forms. It combines the physical properties of SMA and polyurethane foam to create a surface that can be electronically controlled to deform and come back to its original state. Although limited to homeomorphic shape changes, Surflex constitutes an interesting development for how to employ the new materials. The authors describe the implementation addressing the possibilities opened by the use of smart materials and soft mechanics in designing physical interfaces. Another interesting tool is Intuino [26], an authoring tool. The system enables the designers to concentrate on their essential work of interaction design making the prototyping process stronger and also facilitating it. It was created with the coordination of smart materials in mind and designed to allow a easier working with them, cooperating and coordinating the works with Surflex [3].

Successively, Parkes and Ishii [17] presented a more complete design tool for motion prototyping and form finding, named Bosu. Bosu consists of a series of flexible elements that can be physically manipulated. They are composed of various materials, both soft and rigid: textiles, propylene or multiple layers of felt and polyester to allow bending and twisting. The physical manipulations can then be played back thanks to muscle wires embedded in the modules. Even if [28] does not include a methodology for interacting with the material, the authors introduce a possible way on how to incorporate SMA in 3D-printed (elastomeric) structures creating smart structures that can serve as sensor or actuator, by printing the material around the SMA or embedding them in a second time. This would open a lot more possibilities in the close future.

4.3 Other support materials

A more haptic oriented proof of concept for interaction is POC [29]. POC is a surface element made of addressable arrays of two-way SMA springs which can operate at a lower voltage and temperature compatible with mobile devices. The device is capable of changing into different shapes. It can simultaneously realize multiple methods for conveying information using dimension, force, texture and temperature. Wakita [27] takes a very different approach to the material, experimenting and describing his recipe to create a perfect match material for a rheologic interface. Programmable blobs is an actuated shape display. It is based on ferromagnetic fluids that by being attracted, connecting and dividing create a language for transformation control.

5. DISCUSSION AND CONCLUSIONS

We showed how researchers have, up to now, developed SMIs and we have acquired an overview about the use of smart material in each of them. All the discussed papers present different techniques of employing smart materials in interaction design. Our overview shows that only a small subset of the aforementioned materials are used in practice. This is due to several reasons, ranging from too high cost, difficulty to purchase the material or complex employment condition.

In the majority of the works described above we can note some common pattern of production. Many of them used paper or cardboard supports and created interaction based on objects that can be found in the office. Recently the number of papers focussing on interfaces involving smart materials has grown and many of them utilized instruments such as Arduino and Processing. Arduino for hardware controls and coupling it with Processing for the software side. We suppose that the availability and easiness of use, also possibly the amount of related information that can be found online, make them the perfect tools for rapid prototyping.

Even if in Physical Computing [15] is said that smart materials are both difficult to apply and not cheap. We wanted to show that there are techniques that allow both cheap and fast development of interfaces. Some of these methods require a few more technical skills and patience than others. Nevertheless, they are well described and generally easy to replicate. Also, most of the new materials go directly into the market of electronics, but new ways of prototyping are becoming available to the consumer market. The spread of movements like DIYers (people that practice the DIY way) and the increasing availability of home self production tools such as 3D printers will allow more development in this field for personal fabrication [14]. As it has been shown in [28], by enriching the printed elements with smart materials we can create new properties and convey new messages with the interface.

The works addressed above come from a mix of scientific and artistic specialities and from the use of the material itself across different research areas and skills. By pursuing this kind of research we can create methodologies to develop and distribute different kinds of interfaces that can be part of our daily life (by means of automation provided by the home production technologies that are arising nowadays). There are a lot of neglected smart materials on the list, they could offer new and, even if challenging, very satisfactory findings. We can conclude that it is essential that we create more methodologies for creating structures and new ways for interacting with them. It is necessary to be prepared and continue to research and think of ways to use it when it becomes available, as has already happened with e-ink and with OLEDs. This is the tip of the iceberg, with more knowledge we can do a lot more. We would like to close with this: in 2009 Parkes and Ishii [16] suggested that in the future we will "think of the interface as a material itself" and we can add that this is the essential definition of SMI.

6. ACKNOWLEDGMENTS

This publication was supported by a CTIT-ITC collaboration project.

7. REFERENCES

[1] M. Addington and D. L. Schodek. *Smart materials and new technologies : for the architecture and design professions*. Elsevier, Amsterdam, 2005.

[2] M. Coelho, L. Hall, J. Berzowska, and P. Maes. Pulp-based computing: a framework for building computers out of paper. In *CHI '09 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '09, pages 3527–3528, New York, NY, USA, 2009. ACM.

[3] M. Coelho, H. Ishii, and P. Maes. Surflex: a programmable surface for the design of tangible interfaces. In *CHI '08 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '08, pages 3429–3434, New York, NY, USA, 2008. ACM.

[4] S. Delle Monache, D. Rocchesso, J. Qi, L. Buechley, A. De Götzen, and D. Cestaro. Paper mechanisms for sonic interaction. In *Proceedings of the Sixth International Conference on Tangible, Embedded and Embodied Interaction*, TEI '12, pages 61–68, New York, NY, USA, 2012. ACM.

[5] M. Harris, B. Buxton, W. T. Freeman, H. Ishii, M. Lucente, and M. J. Sinclair. Interfaces for humans (panel): natural interaction, tangible data, and beyond. In *ACM SIGGRAPH 98 Conference abstracts and applications*, SIGGRAPH '98, pages 200–202, New York, NY, USA, 1998. ACM.

[6] H. Ishii. Tangible bits: beyond pixels. In *Proc. of TEI'08*, TEI 08, pages xv–xxv, New York, NY, USA, 2008. ACM.

[7] H. Ishii and B. Ullmer. Tangible bits: Towards seamless interfaces between people, bits and atoms. In *CHI'97*, pages 234–241, 1997.

[8] R. J. e. a. Jacob. Reality-based interaction: a framework for post-wimp interfaces. In *Proc. of CHI'08*, CHI '08, pages 201–210, New York, NY, USA, 2008. ACM.

[9] S. Jacoby and L. Buechley. Drawing the electric: storytelling with conductive ink. In *Proceedings of the 12th International Conference on Interaction Design and Children*, IDC '13, pages 265–268, New York, NY, USA, 2013. ACM.

[10] N. Koizumi, K. Yasu, A. Liu, M. Sugimoto, and M. Inami. Animated paper: A toolkit for building moving toys. *Comput. Entertain.*, 8(2):7:1–7:16, Dec. 2010.

[11] D. A. Mellis, S. Jacoby, L. Buechley, H. Perner-Wilson, and J. Qi. Microcontrollers as material: crafting circuits with paper, conductive ink, electronic components, and an "untoolkit". In *Proceedings of the 7th International Conference on Tangible, Embedded and Embodied Interaction*, TEI '13, pages 83–90, New York, NY, USA, 2013. ACM.

[12] A. Minuto and A. Nijholt. Growing grass: a smart material interactive display, design and construction history. In *Proceedings of the 1st workshop on Smart Material Interfaces: A Material Step to the Future*, SMI '12, pages 7:1–7:5, New York, NY, USA, 2012. ACM.

[13] A. Minuto, D. Vyas, W. Poelman, and A. Nijholt. Smart material interfaces: A vision. In *Proc. 4th International ICST Conference on Intelligent Technologies for Interactive Entertainment (INTETAIN 2011)*, LNICST 78, pages 57–62. Springer, 2011.

[14] C. Mota. The rise of personal fabrication. In *Proceedings of the 8th ACM conference on Creativity and cognition*, C&C '11, pages 279–288, New York, NY, USA, 2011. ACM.

[15] D. O'Sullivan and T. Igoe. *Physical Computing: Sensing and Controlling the Physical World with Computers*. Thomson Course Technology, Boston, Massachusetts, May 2004.

[16] A. Parkes and H. Ishii. Kinetic sketchup: motion prototyping in the tangible design process. In *Proceedings of the 3rd International Conference on Tangible and Embedded Interaction*, TEI '09, pages 367–372, New York, NY, USA, 2009. ACM.

[17] A. Parkes and H. Ishii. Bosu: a physical programmable design tool for transformability with soft mechanics. In *Proceedings of the 8th ACM Conference on Designing Interactive Systems*, DIS '10, pages 189–198, New York, NY, USA, 2010. ACM.

[18] A. Parkes, I. Poupyrev, and H. Ishii. Designing kinetic interactions for organic user interfaces. *Commun. ACM*, 51(6):58–65, June 2008.

[19] H. Perner-Wilson, L. Buechley, and M. Satomi. Handcrafting textile interfaces from a kit-of-no-parts. In *Proceedings of the fifth international conference on Tangible, embedded, and embodied interaction*, TEI '11, pages 61–68, New York, NY, USA, 2011. ACM.

[20] J. Qi. Crane tutorial. `http://hlt.media.mit.edu/?p=1448?`, 2010. [Online; accessed July-2013].

[21] J. Qi and L. Buechley. Electronic popables: exploring paper-based computing through an interactive pop-up book. In *Proceedings of the fourth international conference on Tangible, embedded, and embodied interaction*, TEI '10, pages 121–128, New York, NY, USA, 2010. ACM.

[22] J. Qi and L. Buechley. Animating paper using shape memory alloys. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '12, pages 749–752, New York, NY, USA, 2012. ACM.

[23] M. Satomi and H. Perner-Wilson. How to get what you want. `http://www.kobakant.at/DIY/`, 2008. [Online; accessed July-2013].

[24] G. Saul, C. Xu, and M. D. Gross. Interactive paper devices: end-user design & fabrication. In *Proceedings of the fourth international conference on Tangible, embedded, and embodied interaction*, TEI '10, pages 205–212, New York, NY, USA, 2010. ACM.

[25] R. Vertegaal and I. Poupyrev. Introduction. *Commun. ACM*, 51(6):26–30, June 2008.

[26] A. Wakita and Y. Anezaki. Intuino: an authoring tool for supporting the prototyping of organic interfaces. In *Proceedings of the 8th ACM Conference on Designing Interactive Systems*, DIS '10, pages 179–188, New York, NY, USA, 2010. ACM.

[27] A. Wakita, A. Nakano, and N. Kobayashi. Programmable blobs: a rheologic interface for organic shape design. In *Proceedings of the fifth international conference on Tangible, embedded, and embodied interaction*, TEI '11, pages 273–276, New York, NY, USA, 2011. ACM.

[28] P. Walters and D. McGoran. Digital fabrication of smart structures and mechanism: Creative applications in art and design. In *Society for Imaging Science and Technology*, NIP27: International Conference on Digital Printing Technologies and Digital Fabrication, pages 185–188, USA, 2011. The Society for Imaging Science and Technology.

[29] H. Wang, D. Kaleas, R. Ruuspakka, and R. Tartz. Haptics using a smart material for eyes free interaction in mobile devices. In *Haptics Symposium (HAPTICS), 2012 IEEE*, pages 523–526, 2012.

[30] M. Weiser. The computer for the 21st century. *Scientific American*, 265(3):94–104, 1991.

[31] T. Wrensch and M. Eisenberg. The programmable hinge: toward computationally enhanced crafts. In *Proceedings of the 11th annual ACM symposium on User interface software and technology*, UIST '98, pages 89–96, New York, NY, USA, 1998. ACM.

[32] K. Zhu and S. Zhao. Autogami: a low-cost rapid prototyping toolkit for automated movable paper craft. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '13, pages 661–670, New York, NY, USA, 2013. ACM.