Thermochromic Information Surfaces

Interactive Visualization for Architectural Environments

David van der Maas¹, Mark Meagher², Christian Abegg³, Jeffrey Huang⁴
Ecole Polytechnique Fédérale de Lausanne, Switzerland
http://ldm.epfl.ch
¹david.vandermaas@epfl.ch, ²mark.meagher@epfl.ch,
³christian.abegg@epfl.ch, ⁴jeffrey.huang@epfl.ch

Abstract: In this paper we describe a series of nine prototypes that were constructed to explore the benefits and limitations of thermochromic ink as a material for the design of architectural information surfaces. Among the goals of the project were the identification of inexpensive fabrication methods that could be used to build thermochromic surfaces at the scale of a room. Our primary design concerns were the ability to communicate information about indoor climate, and the integration of the information surfaces in an architectural environment. We propose a method for building thermochromic surfaces based on printed circuit boards (PCB) that is cost-effective, highly precise, and allows the fabrication of large surfaces through tiling.

Keywords: Thermochromic display; interactive architecture; information visualization; fabrication process; communication.

Introduction

Thermochromism is the ability of a substance to change color due to a change in temperature. Thermochromic pigments have a large range of possible color, and sensitively register changes in temperature by changing color or becoming transparent at a precisely-determined threshold temperature. The change is reversible, and can be repeated over long periods of time without substantial degradation in the pigment’s thermochromic properties (Christie et al, 2007).

We first became interested in architectural applications of thermochromic pigments while searching for options to display information about indoor air quality (luminosity, humidity, temperature, CO₂, dust, ...) in a workplace environment. Our goal was to build a panel with graphic elements that could be selectively turned on and off to communicate indoor climate parameters (Meagher et al, 2009). For a number of reasons, thermochromic ink was chosen for this application. First, it is non-emissive and thus less distracting than LED or other emissive displays in an architectural environment: the contrast increases with the environmental light level (natural or artificial light), unlike light-emitting displays that have to compete with daylight. The graphic element can be made visible from both sides of the display, and can also be molded in various shapes. The relatively low refresh rate (the surface needs several seconds to cool down) is well-adapted to the representation of data that do not change quickly, like air quality parameters.

There are only few research papers describing
architectural applications of thermochromic pigments. Some attention has been given to the development of architectural glazing incorporating thermochromic pigments that rejects unwanted solar heat gain while maximizing daylighting (Seebeth et al, 2000; Fernandez, 2007). Thermochromic pigments have been used in many product design applications including fabrics capable of dynamic color change (Berzowska, 2004) and as a means of designing ‘smart textiles’ that respond to changes in their environment (Christie et al, 2007).

The use of thermochromic pigments for information display has been reported for very small displays (Liu et al, 2007) or low resolution outputs (http://www.we-make-money-not-art.com/archives/2004/07/notsowhite-walls-interactive-w.php: Jul 2004).

Various fabrication technologies have already been explored for selective heating of the thermochromic surface:

- Conductive particles mixed with other materials (Liu et al. 2007),
- Conductive yarns (Shibutani & Wakita, 2006),

We decided to explore the use of printed circuits boards (PCB) to fulfill this task. PCB is commonly used for electrical circuits and allows patterns to be etched in the copper layer covering an epoxy plate. This technology which is used worldwide makes it possible to realize detailed etching patterns with an almost complete freedom in design.

### The fabrication of a thermochromic panel prototype

For this study we built a set of nine prototype panels: seven were the size of an A4 paper sheet and two panels had a display surface area of 0.48m² (0.74 by 0.64 m).

We used a thermochromic reversible leucodye micro-capsules based ink which is blue below 40°C and transparent above this temperature. The temperature threshold of the thermochromic pigments can be freely defined on order, between -15°C and 80°C. Our goal was to use this property to display information by selectively heating an ink covered panel above the threshold temperature.

The PCB fabrication facility of our university allows patterns to be made with a linewidth of about 0.1mm (the order of size of a human hair). The boards used have a copper layer thickness in the range 5 to 18 micrometer. The thickness of the epoxy substrate was chosen depending on the prototype and was in the range of 1.6 to 0.1mm. The 0.1mm substrate board was as flexible as a sheet of paper and could easily be molded to a curved surface such as a structural column (figure 1f).

When we apply an electrical voltage at both ends of a conductive element, it will heat, in turn heating the painting and cause a change in the color of the ink with which it is in contact.

The figure to be displayed could be designed as an outline (figures 1c, 1d, 1e, 1f) or a filled in figure (figures 1g, 1h, 1i, 1j, 1k). In order to display a filled in figure, the pattern on the PC board consisted of a coiled wire filling in precisely the surface area of the figure. The line width and length of the heating elements were adjusted to reach an optimum electrical resistance and be compatible with the requirements of the power supply. Because of the low value of the electrical resistivity of copper, the linewidth was in general chosen as small as possible while still easy to manufacture.

We were able to build boards with a maximum dimension of 23 x 30cm using standard processes;
Figure 1
Thermochromic prototypes:

a, b: This design, borrowed from a fabric pattern by Klaus Haapaniemi, uses density and brightness as variables to communicate information, for example change in indoor climate.

c: Our prototype implementing the concept of figure b, fixed on a frame, hanging on the wall (display surface of 64cm x 76 cm)

d, e: Outline figures. Close-up of the pattern displayed on the wall panel. Bird (30cm x 30cm), ostrich (10cm x 8cm).

f: Same panel as in c, but wrapped around a column

g, h, k: Filled in figures. RSS icon (4cm x 4cm), arrow (~18cm x 7cm), wastebasket (17cm x 14cm)

i: Overlapping patterns

j: Pixel board prototype, the PCB before being covered with paint (256 pixels of one square centimeter).
larger panels could be constructed by tiling these boards together, and two of our prototypes were built with four boards each to form an apparently homogeneous surface of almost 0.5m².

Among the advantages of PCBs for our application were the flatness and the smoothness of the surface in contrast with glued conductive materials such as nichrome wire. To assure high contrast, we first applied a layer of white paint on the boards before adding the blue: when the blue thermochromic paint is heated it becomes transparent and the white paint becomes visible.

The idea is to use a convenient voltage, to limit risks of overheating of the circuits and to simplify the power management. So the circuits' length should be adapted to the available voltage. Tests were made using either DC or PWM (Pulse-width modulation) power supplies. The current depends on the PCB characteristics chosen.

The first prototypes explored the use of conductive pixels (figure 1j) to activate the thermochromic pigment: we realized an array of 16 x 16 pixels (1 x 1cm), each of which contained ~40cm of tightly coiled copper lines in order to reach an optimal resistance for heating. The activated pixels provided a high level of contrast and legibility from a distance, but we were not satisfied with the aesthetic quality of the visualizations obtainable using such a small pixel array.

Following the pixel display, we tried “filled shapes” (figures 1g, 1h, 1i, 1k) with several boards that used commonly recognizable icons to communicate information. We experimented with the spacing of the copper wires used to activate the filled shape, and found that the spacing had a direct effect on the color and brightness of the resulting shape. We explored the design possibilities afforded by overlapping several figures on a board, either by printing circuits on both sides of the PCB or by interleaving one circuit with another on a single-sided board (figure 1i).

Our final set of prototypes explored the use of “outline only shapes” and “patterns” - figures formed by a single copper wire. We found these outline-figures particularly appealing in that they compared favorably to an LCD display in terms of resolution, because the unit of display was now a line rather than a pixel.

**Discussion**

One advantage of thermochromic panels is the fact that the power consumption is not dependent on the total surface area of the display, but rather on the power required to turn on the desired pattern: unlike LCD’s, no power is required when no content is being displayed. And even switched on, the power consumption of our large prototypes, is competitive with a LCD display of the same size. A LCD display of a size equivalent to our largest board (~0.5m²) has a typical power consumption of 200W-400W. With all the patterns switched on, our board has a power consumption around 100W.

In terms of design, the possible patterns displayed are fixed for the lifetime of the product. They have to be defined when the board is ordered. This makes them specially adapted to visualization interfaces displaying a fixed kind of information.

Thermochromic surfaces are particularly suited for uses that do not require frequent changes in the displayed content, and can be especially valuable for environments where subtle, non-intrusive information visualization surfaces are required. When parts of the surface are switched off after being activated, the patterns gradually fade away and the color returns to its initial state, a process that requires several seconds, depending on the ambient temperature and the mechanical properties of the board. This gradual rate of change was seen as a benefit in terms of integrating information displays in the built environment without introducing a source of distraction. The non-emissive property of thermochromic surfaces also contributes to the specific quality of thermochromic displays. Thermochromism may be a valuable answer to information visualization challenges, specially in electromagnetically sensitive
environments like hospital, airplanes, or high-tech labs.

In regard to information visualization, we concluded that pixels are not an ideal method for thermochromic information interfaces, at least as implemented in our prototypes. The use of patterns formed by a single thickness of copper wire is more successful in terms of information display and aesthetic results. The primary benefit of single-wire patterns is the precision of the lines, and the ability to produce a vector figure with the resolution of a printed graphic.

**Conclusions**

For the design of architectural information surfaces we propose a method using the property of thermochromic ink to change color when heated above a threshold temperature. The ink is applied to a thin wire copper pattern etched on a standard PCB board using standard PCB techniques, and heated by passing an electrical current through the wire pattern.

The feasibility of the technique is demonstrated by the construction of nine prototypes with different technical parameter choices. The design parameters can be optimized to improve the display contrast and lower the power consumption. The manufacturing costs can be reduced by volume production.

In terms of architectural integration, the primary goals of the project were to reduce the cost of fabrication, to maximize the surface area of the display, and to identify techniques for the display of information that would be minimally distracting in a workplace environment. It was shown that the display surface area can be increased by tiling A4 size boards together. The prototype was made up out of four boards with a display area of 0.48m².

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**References**


