# Inkantatory Paper: Dynamically Color-changing Prints with Multiple Functional Inks

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**(a)** **(b)**

**Figure 1. Inkantatory Paper. (a) Changing color by touch. (b) Changing color of paper crafts. It is caused by change of temperature, as shown in the thermal images at right.**

**ABSTRACT**

We propose an effective combination of multiple functional inks, including conductive silver ink, thermo-chromic ink, and regular inkjet ink, for a novel paper-based interface called Inkantatory Paper that can dynamically change the color of its printed pattern. Constructed with off-the-shelf inkjet printing using silver conductive ink, our system enables users to fabricate thin, flat, flexible, and low-cost interactive paper. We evaluated the characteristics of the conductive silver ink as a heating system for the thermo-chromic ink and created applications demonstrating the usability of the system.

**Author Keywords**

Paper computing; conductive ink; prototyping; flexible printed electronics; inkjet printing; digital fabrication.

**ACM Classification Keywords**

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


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## INTRODUCTION

Paper is used for a variety of purposes such as writing, reading, folding, packing, and so on, and recently there have been a number of studies on the augmentation of paper's function [1].

In 2012, Mitsubishi Paper Mill, Ltd. released commercial silver nano-particle inks [2] that are essentially conductive inks enabling inkjet printing of electrical circuits on paper or plastic film. Owing to this innovation, rapid prototyping of ubicomp devices is now attracting a lot of interest [3]. For example, Electronic Popables is an interactive pop-up book that sparkles, sings, and moves [4].

The focus of these studies has mainly been input techniques including touch, pressure, and bend sensing. In this work, however, we focus on output techniques, specifically, for a dynamic visual displaying method. For this purpose, we propose an effective combination of multiple functional inks including conductive silver ink, thermo-chromic ink, and regular inkjet ink. Our key concern in this paper is how to utilize the conductive silver ink as a heating system for the thermo-chromic ink. Constructed with off-the-shelf inkjet printing using silver conductive ink, our system enables users to fabricate thin, flat, flexible, and low-cost interactive paper that we call Inkantatory Paper. Our aim is to provide users with an easy way of integrating computing with paper.

We demonstrate two applications, as shown in Figure 1: (a) a printed fire image changing from black to red in response to a user's touch, and (b) the colors of paper crafts change according to the temperature as shown in the thermal image.

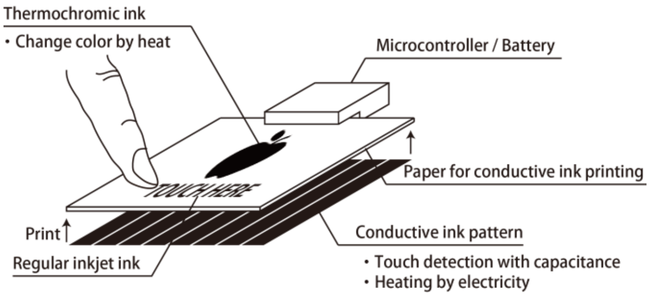


**Figure 2: System overview.**

## SYSTEM OVERVIEW

The flow of this system includes three steps: 1) constructing the layout of the color-changing area and printing the pattern using an inkjet printer (PIXUS iP100) with conductive silver ink (MU01, Mitsubishi Paper Mill, Ltd.), 2) printing or painting with thermo-chromic ink (THERMO-CHROMIC Pigments 39°C, QCR Solutions Corp.), and 3) adding microcontroller and a power source. The system overview is detailed in Figure 2.

### Layout and printing of conductive silver ink

To construct an adequate heating and touch detection system, we designed pre-composed patterns of conductive silver ink. Users can create their own heating patterns using a combination of these pre-composed patterns.

### Painting thermo-chromic ink

Users can print the thermo-chromic ink on the backside of the printed heating pattern by using a screen printing kit or by hand-painting with brushes. We selected thermo-chromic ink with an activation temperature of 39°C in order to avoid the effect of body temperature and made sure that it did not go higher than 44°C to avoid harming users.

### Hardware and power source design

We evaluated the relationship between the response speed of heat and the electricity consumption per unit area to design the hardware. Conductive silver ink patterns with 0.05–0.6 $W/cm^2$ were electrified and the time taken to reach the target temperature was measured. We utilized 200-µm non-layered paper and 270-µm-thick sticker-coated paper. The conductive silver pattern had a line width of 1 mm with 0.25-mm spacing between lines. The time taken to attain a temperature 10°C or 20°C higher than the original temperature is shown in Figure 3. As an example, 0.15 $W/cm^2$ of power is required to heat up 200-µm-thick paper by 10°C in three seconds. This means that one lithium polymer battery, which has 3 W of power, can heat up a 20-$cm^2$ area in this situation.

For the hardware in this research, we utilized the Arduino capacitive sensing library as input. This library requires an Arduino and 10 MΩ resistors, which we connected to paper with magnets.

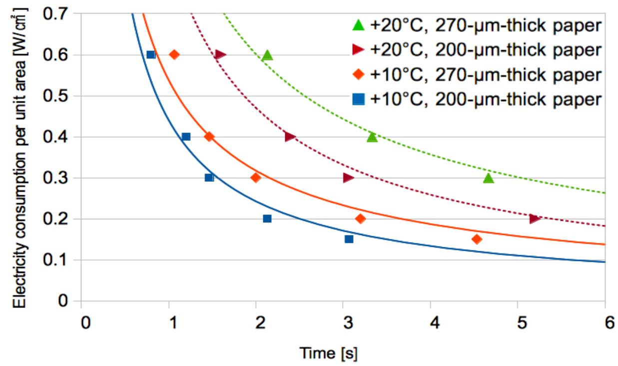


**Figure 3: Characteristics of conductive silver ink as a heating system.**

## APPLICATION

In this section, we demonstrate 3 applications to showcase the capabilities of Inkantatory paper: a digital clock, a dynamic questionnaire, and a color-changing paper craft.

Digital clock: Inkantatory paper can be applied to ambient devices such as a clock because it displays reflected ambient light.

Dynamic questionnaire: Our system maintains the color of selected choices by providing continuous heat. Also, by adding a microcontroller and a battery to a magnet clip, it can function as a stand-alone system.

Paper craft: Since Inkantatory paper is composed of paper and inks, it is thin, flat, and flexible enough to make paper crafts.

## CONCLUSION

This paper presented Inkantatory Paper, which adds a color-changing function to paper fabrications. We evaluated the relationship between the response speed of heat and the electricity consumption per unit area to design a given piece of hardware.

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