Prototyping an Urushi Display that Changes Color Interactively by Temperature Control

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***Abstract*—Urushi is a type of natural resin paint. It has been traditionally used to coat wooden crafts to protect them from degradation. A craft coated with urushi, called urushi-ware, has been used for centuries for daily necessities and has aspects of a work of art because it has a beautiful gloss and smooth feel on the surface. The goal of our study is to develop a set of techniques that allow designers to fabricate an urushi-ware with true interactivity, which can present visual information to provide an urushi-ware with both inputs and outputs while maintaining a beautiful gloss and a smooth feel on the surface. In this study, to achieve the above goal, we developed a technique for presenting visual information on urushi-ware. We create thermochromic colored urushi by mixing thermochromic pigments with a "Clear Urushi". We conducted a pilot study to quantitatively evaluate the color change of thermochromic colored urushi with temperature. The result suggests that people could perceive a color change in thermochromic colored urushi.**

***Index Terms*—colored urushi, thermochromic pigments, multilayered urushi circuit, fabrication, urushi-ware**

I. Introduction

Urushi (Japanese lacquer) is a type of natural resin paint. It has been traditionally used to coat wooden crafts such as furniture and dishes mainly to protect them from degradation, taking advantage of urushi's durability, waterproofness, and antibacterial property. Therefore, a craft coated with urushi, called urushi-ware, has been used for centuries for daily necessities, such as bowls, plates, and stacked boxes. In addition, an urushi-ware has an aspect as a work of art because it has a beautiful gloss and a smooth feel on the surface.

The goal of our study is to develop a set of techniques that allow designers to fabricate an urushi-ware with true interactivity, which can present visual information to provide an urushi-ware with both inputs (e.g., user's touch, sensor values, and current time) and outputs (feedbacks on that inputs) while maintaining a beautiful gloss and a smooth feel on the surface. Previously, some studies have developed techniques to add touch sensitivity to an urushi-ware [1]–[4]. However, these techniques used an urushi-ware only as an input device; interactions in response to the input were performed on a PC or smartphone.

In this study, to achieve the above goal, we developed a technique for presenting visual information on urushi-ware, which can be used in combination with the above input techniques [1]–[4]. We focused on patterns such as clouds, ripples, and plants, used to decorate traditional urushi-ware. These patterns on a conventional urushi-ware are immutable and are fixed to particular patterns. Our idea is to control urushi's color and, thus, the patterns of urushi-ware dynamically, which realizes an urushi-ware with which users can enjoy a variety of patterns on a single urushi-ware. This enables visual feedback for interactions with the urushi-ware. To this end, we created thermochromic colored urushi by mixing thermochromic pigments with a "Clear Urushi", i.e., a translucent amber urushi. Using this colored urushi, we can maintain a beautiful gloss and a smooth touch.

With our techniques, designers can fabricate a vase that changes its color depending on the amount of water (Fig. 1a); when the water level is insufficient, the color of the vase becomes red to warn the user to fill it; the color returns to normal when the user adds more water to the right level. Designers can also fabricate a plate that can decorate food on it (Fig. 1b); when the user places food on the plate, a pattern appears. As another example, designers can fabricate a bowl that changes color depending on the temperature of the liquids inside (Fig. 1c); when the contents cool, the bowl changes its color to let the user know the contents' temperature has reached a desirable temperature. Moreover, designers can also fabricate a digital alarm clock that changes its surface pattern when touched (Fig. 1d); when the user stops the alarm, a pattern appears on the clock's top and sides' surface.

The contributions of this paper are as follows:

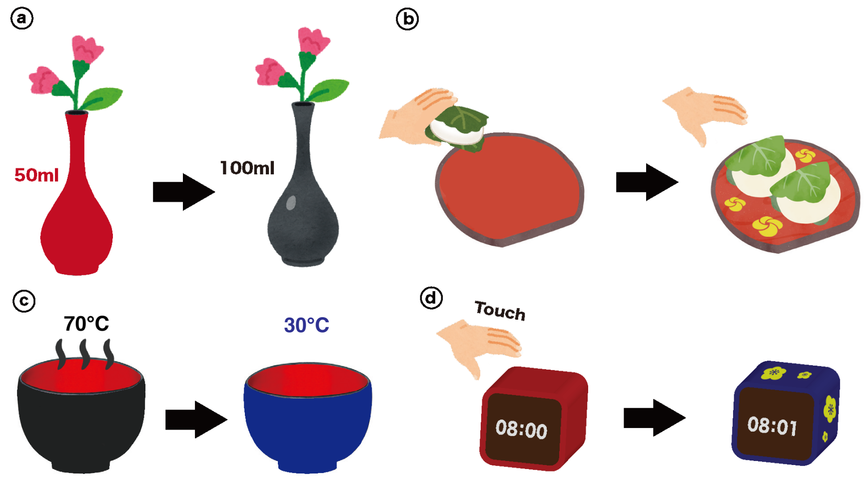

Fig. 1. Application examples: a) a vase that changes its color depending on the amount of water, b) a plate with patterns that appear when food is placed on it, c) a bowl that changes color depending on temperature, and d) a digital alarm clock that changes its surface pattern when touched.

- We developed a technique that uses thermochromic colored urushi for presenting visual information on urushi-ware while maintaining its beautiful feel and smooth touch.
- We tested the technique by fabricating a prototype of urushi display.
- We showed that people perceive the color difference before and after heating the thermochromic colored urushi.

II. Related Work

Input devices made of urushi have been developed. Suzuki [4] fabricated an 'urushi musical interface,' whose surface has touch-sensitive electrodes made of gold on its surface.

One of the properties of urushi is its insulating property, which highly contributes to the interactivity of urushi-ware. Hashimoto et al. [1] showed that it is possible to construct an urushi circuit using urushi as an insulating base material and a coating material for electronic circuits. Moreover, they also showed that it is possible to layer an urushi circuit multiple times (multilayered urushi circuit). Some studies used multilayered urushi circuits to add input capability to urushi-ware [2], [3]. Ikegawa et al. [2] and Saito et al. [3] embedded touch-sensitive electrodes and an NFC antenna, respectively, into the urushi-ware, maintaining a beautiful gloss and a smooth feel on the surface. However, these studies used an urushi-ware only as an input device; interactions in response to the input were performed on a PC or smartphone. By contrast, in this study, we focus on developing techniques that allow designers to fabricate an urushi-ware that can also present visual information, maintaining a beautiful gloss and a smooth feel on the surface.

To develop techniques to fabricate an urushi-ware that can present visual information while maintaining a beautiful gloss and a smooth feel on the surface, we first considered embedding the following three types of displays into urushi-ware because of their thinness: electroluminescence [5]–[9], electrochromic [10]–[12] or thermochromic [13]–[19] displays. However, electroluminescent and electrochromic displays require safety considerations because of hazardous substances in the fabrication process. In contrast to these two types of displays, thermochromic displays have relatively little impact on the human body and the environment during the fabrication process. Thermochromic pigments change color when the temperature changes and many have thermochromic reversibility. In addition, thermochromic pigments have a high coloring power. Furthermore, there is a type of urushi called colored urushi in which pigments (e.g., lake pigments) are mixed with the urushi to color it. For these reasons, we chose thermochromic displays, which can be produced with pigments and do not emit light, for maintaining the characteristics of urushi-ware with deep, low-saturation colors.

In research using thermochromic displays, Roshan et al. [18] presented a touch sensing mechanism using a temperature-based touch sensor based on thermochromic ink and Peltier element. They also implemented a non-luminescent textile display using this sensor. ChromoSkin [16] is a makeup system that can dynamically change its color. As a prototype of ChromoSkin, Kao et al. created an eyeshadow composed of thermochromic pigments that changed color depending on the temperature. Other examples include HeartMe [15], a system for inducing awareness of heart disease using thermochromic displays, and AmbiKraf [19], a non-luminescent fabric display that changes color rapidly using thermochromic ink and Peltier devices. We thought that thermochromic pigments could be used for urushi in the same way as in these studies to change the color and pattern of urushi-ware.

III. Concept of Our Prototype

Fig. 2 shows the concept of our urushi display. An urushi display consists of three layers: a thermochromic colored urushi layer, a heater pattern layer, and a wiring layer.

The thermochromic colored urushi layer serves as a display. It is created by mixing clear urushi and thermochromic pig-

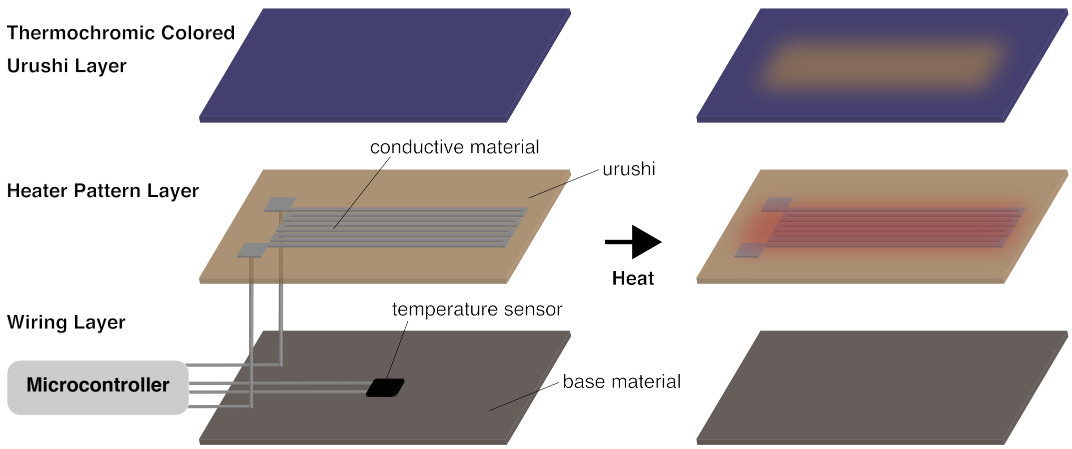

Fig. 2. Concept of urushi display. Urushi display consists of three layers: thermochromic colored urushi layer, heater pattern layer, and wiring layer.

ments. The color of this layer changes when heat is applied because of the effect of the thermochromic pigments.

The heater pattern layer has a one-stroke pattern with a conductive material (e.g., conductive ink, conductive paste, and conductive foil). This pattern serves as a heating wire when a current is applied. It generates heat as in [20], making it possible to change the color of the thermochromic colored urushi layer depending on the pattern.

The wiring layer is a layer that connects the heater pattern and microcontroller. The heater pattern layer and the wiring layer are electrically insulated by inserting urushi between them with a multilayered urushi circuit. A temperature sensor is also placed on the wiring layer, which is used for feedback control.

IV. Implementation of Our Prototype

We show the fabrication process of the thermochromic colored urushi display and the implementation of the temperature control circuit.

A. Fabrication Process of Thermochromic Colored Urushi Display

Fig. 3 shows the fabrication process of the thermochromic colored urushi display.

First, we fabricated a thermochromic colored urushi layer. We prepared clear urushi (Minowa Shikko Co. Ltd, Glossy) and thermochromic pigments (Recording Material Research Institute K. K., Thermal Color) in a mass ratio of 1:1, as the same as for fabricating regular colored urushi (Fig. 3a). Then, we mixed them well with a spatula for approximately five minutes until the thermochromic pigment was free of particles (Fig. 3b). After mixing, we coated the acrylic plate with the colored urushi using a bar coater (TQC Sheen), a device for applying a liquid paint in a uniform thickness; the thickness was adjusted by the speed of the bar coater (Fig. 3c and d). We hardened the colored urushi in a humidifier (ESPEC SH-222) with a humidity of around 60% for a day (Fig. 3e); urushi hardens by absorbing moisture in the air.

Next, we fabricated the heater pattern layer on the thermochromic colored urushi layer. We used silver foil as a heater pattern. The heater pattern was designed using Adobe Illustrator. In this study, we designed a flower, a cloud, and one of the Japanese family crests, traditional Japanese patterns used to identify families, for testing our technique. In this section, we explain the fabrication process of the display using a flower pattern (Fig. 3f). We pasted silver foil with 5.4 μm thickness on the thermochromic colored urushi using a foil stamping machine (DGSHAPE LD-300) in the shape of these patterns (Fig. 3g). Fig. 3h shows the results of pasting the silver foil in the shape of a flower pattern. Then, we coated clear urushi on the heater pattern and hardened it like when we coated the colored urushi (Fig. 3c) to protect the heater pattern from deterioration and to electrically insulate the heater pattern against the wiring layer (Fig. 3i). Note that the clear urushi turns the display a reddish color.

Finally, we fabricated the wiring layer. Through holes were created by scraping the surface of the urushi at both ends of the heater pattern using a handy router machine (Fig. 3j), and both ends of the heater pattern were connected to the microcontroller.

B. Temperature Control Circuit

It is necessary to accurately control the temperature for stably changing the thermochromic colored urushi and ensuring the safety of the users touching it. To do this, we used a proportional–integral–derivative control (PID control) as a temperature control. The voltage applied to the heater pattern from the microcontroller (Adafruit Feather 32u4) was adjusted by using the measured value of the temperature sensor (Texas instruments, TMP006) as the input for the PID control, which controls the heater pattern to reach the target temperature. In addition, we added an external power supply (KIKUSUI, PMC18-2) and a relay circuit (Panasonic, AQW210EH) because the current output from the microcontroller was not large enough to heat the heater pattern. The voltage of the external

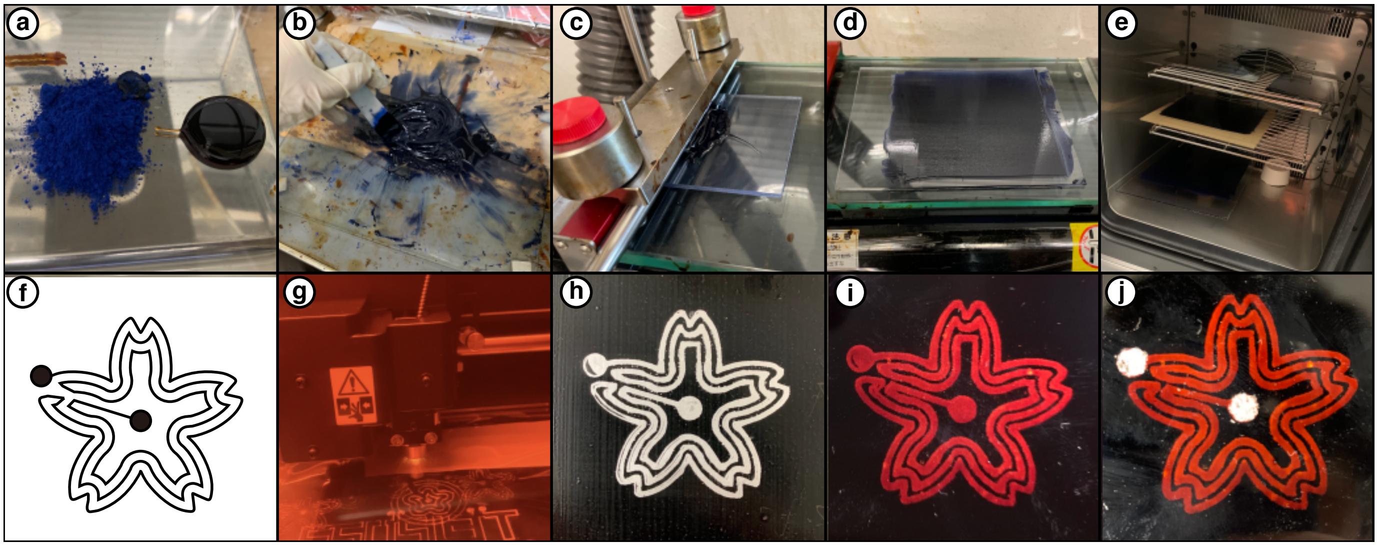

Fig. 3. Fabrication process of the thermochromic colored urushi display.

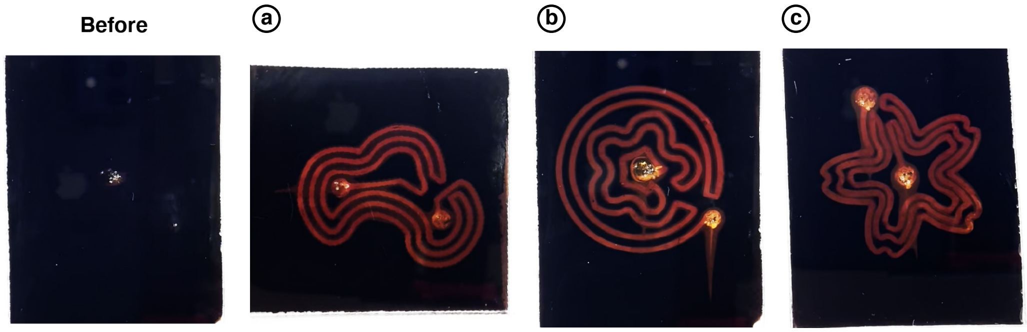

Fig. 4. Color changes of urushi displays before and after heating. We fabricated 3 prototypes of urushi display using heater patterns imitating a cloud (a), a one of Japanese family crests (b), and a flower (c).

power supply was 12 V. The relay circuit was controlled by the voltage output from the microcontroller so that there would be sufficient current flows to heat the pattern.

Fig. 4 shows the color change of the urushi display before and after heating. We fabricated 3 prototypes of urushi display using heater patterns imitating a cloud ($41.5\,\Omega$, Fig. 4a), one of the Japanese family crests ($53.4\,\Omega$, Fig. 4b), and a flower ($49.0\,\Omega$, Fig. 4c) using blue thermochromic pigments (Recording Material Research Institute K. K., Thermal Color), all of which start to become translucent at 30 °C and fully transparent at 40 °C.

V. Pilot Study of The Color Change of Thermochromic Colored Urushi

We quantitatively investigated whether people could perceive the color difference before and after heating the thermochromic colored urushi.

A. Design

We prepared 2 colors (red and blue) $\times$ 3 intermediate temperatures (ITs) (30, 35, and 40 °C) = 6 types of thermochromic pigments (Recording Material Research Institute K. K., Thermal Color). Each pigment starts to become translucent at -5 °C) of its IT and fully transparent at +5 °C) of its IT.

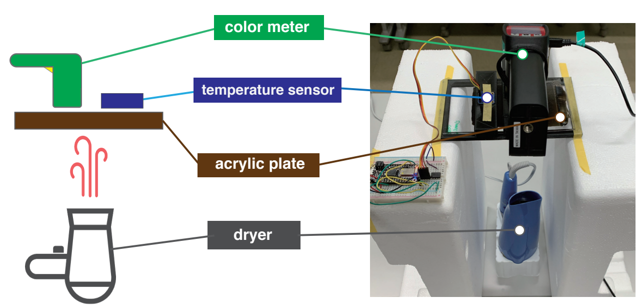

Fig. 5. Experimental equipment for investigating the color change of thermochromic colored urushi.

We made the thermochromic colored urushi using these pigments and coated the acrylic plate with the colored urushi in the same process as Section IV-A with a bar coater at the speed of 2 mm/s. For one day, colored urushi was hardened in a humidifier (humidity: 60%, temperature: 20 °C).

B. Experimental Equipment

Fig. 5 shows the experimental equipment. We fixed the acrylic plate with the painted surface facing up using a fixture. Then, we placed a noncontact temperature sensor (Texas instruments,TMP006) 1 cm above the thermochromic colored urushi to measure the surface temperature. We used a dryer (Panasonic,EH5101P) to raise the temperature by blowing air under the acrylic plate. Since the pigments we used had three ITs, the temperature needed to be adjusted according to their ITs. For this adjustment, we set the height from the dryer to the acrylic plate as follows for each IT: 16 cm when the IT was 30 °C, 11.6 cm when the IT was 35 °C, and 9.4 cm when the IT was 40 °C. The color was measured every 3 seconds using a color meter (TES-3250). The room temperature was maintained at 23 °C.

C. Result

Fig. 6 shows the color differences for temperature when the IT of the thermochromic pigments were 30, 35, and 40 °C. The color difference (ΔE) was calculated based on the formula of CIE-76 standard [21], which represents the Euclidean distance in the Lab color space. This metric represents how the human eye perceives the color difference.

The color difference from the start to the end of the color change was linearly distributed, except when the IT was 40 °C and the color was blue. For all ITs, the color change tended to occur at lower temperatures when the color was red compared to when it was blue.

For all ITs and all colors, the color differences before and after completely changing the color ranged from 5 to 7. According to [22], ΔE higher than 2.3 means that the human eye can notice a change of color. Therefore, it is considered that the user can perceive the color change of the thermochromic colored urushi.

VI. Future Work

Currently, the system controls the temperature; when the temperature reaches a certain level, the color changes and a pattern appears. To make it possible for people to interact with the urushi-ware, such as what is shown in Fig. 1a, 1b, and 1d so that the patterns appear when people touch it, we are planning to embed pressure sensors (Fig. 1a and Fig. 1b) and touch sensors (Fig. 1d) by using multilayered urushi circuit [1].

Until now, we used only one type of colored urushi and one type of pattern. This means that the number of patterns on an urushi-ware is limited to two (e.g., the patterns shown in Fig. 4 left and Fig. 4a). In the future, we want to express a variety of patterns by combining multiple types of urushi and patterns. Currently, we are investigating ways to achieve this, such as producing a new thermochromic colored urushi by mixing two or more thermochromic pigments and layering differently colored thermochromic colored urushi layers.

In this work, while we formed a thermochromic urushi display on a flat surface, urushi is also used to coat a curved object (e.g., soup bowl and spoon). Therefore, it is necessary to test a thermochromic colored urushi display on curved objects and investigate its durability.

Also, the results of the pilot study indicated the possibility of expressing intermediate colors with one type of thermochromic pigment. We will investigate how many color levels it can express by controlling the temperature of the heater pattern layer to increase the range of expression per one pigment.

In addition, it is necessary to verify how the physical properties of urushi change over time since we mixed pigments with urushi. For example, although urushi itself bestows durability, it is unknown how well this durability is maintained.

After addressing these technical issues, we plan to make several prototypes, as shown in Fig. 1, and then conduct a workshop to ask participants (especially students and professors in the college of art and design at our university) to use the created prototypes, assess their impression of the prototypes, and elicit future applications.

VII. Conclusion

We presented a technique that uses thermochromic colored urushi for presenting visual information on urushi-ware while maintaining its beautiful feel and smooth touch. A thermochromic colored urushi was created by mixing clear urushi and thermochromic pigments. Our technique can display visual information through the control of the temperature of thermochromic colored urushi. We conducted a pilot study to quantitatively evaluate the color change of thermochromic colored urushi based on temperature. The result suggests that people could perceive a color change in thermochromic colored urushi.

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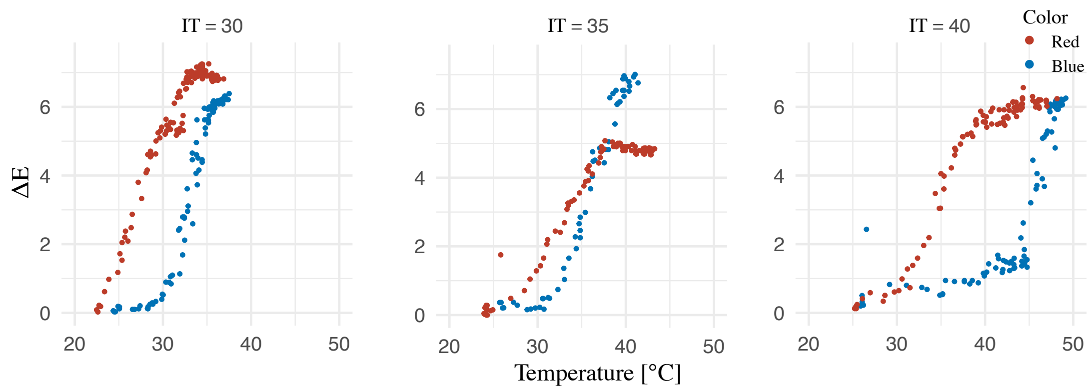

Fig. 6. The results of the color difference based on temperature when the intermediate temperature (IT) of the thermochromic pigments were 30 °C (left), 35 °C (center), and 40 (right) °C.

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