Investigation of Touch Interfaces Using Multilayered *Urushi Circuit*

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Abstract

Urushi (Japanese lacquer) is a natural resin paint with electrical insulating capability. By using it as a base material and coating material for electronic circuits, it is possible to construct a circuit with an elegant appearance and feel. It is also possible to build a multilayered electronic circuit by using *urushi* as insulation layers. In this study, we investigate techniques to construct touch interfaces using a multilayered electronic circuit (*urushi circuit*). At first, we fabricated an *urushi circuit* with a touch electrode consisting of two layers. To improve its appearance, we fabricated *urushi circuits* in which all touch electrodes are arranged on the top layer and all wires are hidden in the bottom layer. Moreover, as an extension of the touch interface, we built a grid of touch electrodes that realizes two-dimensional touch sensing.

Author Keywords

Fabrication; Japanese lacquer; lacquerware; traditional Japanese craft; visual design.

Introduction

Urushi (Japanese lacquer) is a natural resin paint, which is used in traditional Japanese crafts such as furniture and dishes. While *urushi* is famous as a beautiful paint, it also has many useful features such as electrical insulating capability and waterproofness. Owing to these properties, it is possible to construct an electronic circuit with an elegant appearance and feel by using *urushi* as a base material and coating material of electronic circuits [11]. In addition, it is possible to build a multilayered electronic circuit (*urushi circuit*) by using *urushi* as insulation layers as shown in Figure 1. In addition, there is a technique called *makie*, which draws patterns for decoration on the surface of lacquerware (craftwork made by painting *urushi* on wood or paper) by sprinkling metal powder (e.g., gold and silver).

In this study, we are exploring techniques to add interactivity to lacquerware in a visually harmonized way with lacquer, enhancing its elegant appearance and feel. To achieve this, we investigate techniques to incorporate touch electrodes, which are made with *makie* and a multilayered *urushi circuit*, into lacquerware. In particular, circuit patterns made with makie on the *urushi* surface serve as both touch electrodes and components of visual design in our techniques. In addition, we demonstrate techniques to extend the touch interface function to detect touch positions and swipe gestures by separating circuit patterns into each layer of the multilayered *urushi circuit*.

The contributions of this paper are as follows:

1. We demonstrate techniques to construct touch interfaces using an *urushi circuit*.
2. We demonstrate that the overlapping of wires and electrodes does not affect the touch detection of the touch interface on a multilayered *urushi circuit*.
3. We demonstrate the applicability of the *urushi circuit* to a grid of touch electrodes that realizes two-dimensional touch sensing.

Related Work

Many researchers have explored approaches to incorporate a touch interface into visual design. One approach is a technique to construct a touch electrode that can also serve as a component of visual design. For example, Weigel et al. [8] and Lo et al. [1] developed an on-skin touch electrode that is thin, flexible, and visually customizable. Van de Zande et al. [7] proposed touch electrodes that can also display icons using screen printed electroluminescence and conductive ink. Olberding et al. [2] developed a cuttable capacitive multi-touch electrode that is printed with conductive ink. Another approach is supporting users in designing touch-sensitive objects and/or surfaces. For example, Zhang et al. [12] demonstrated a technique that makes various objects and surfaces touch-sensitive using electric field tomography. Savage et al. [3] demonstrated a toolkit to support the design, fabrication, and programming of flexible capacitive touch electrodes for interactive objects. Similarly, Schmitz et al. [4] showed a toolkit to help users fabricate 3D-printed objects with capacitive multi-touch sensing. As compared with these studies, we investigated techniques to incorporate touch electrodes, which are made with *makie* and a multilayered *urushi circuit*, into lacquerware.

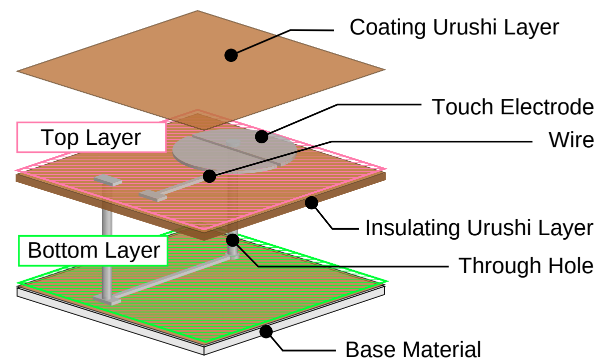

Figure 1: Construction of a multilayered *urushi circuit*.

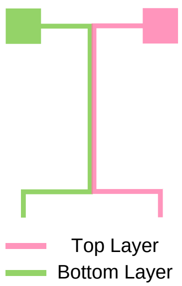

Figure 3: Design of the first prototype consisting of two layers. Two wires connected to touch electrodes were overlapped between the two layers.

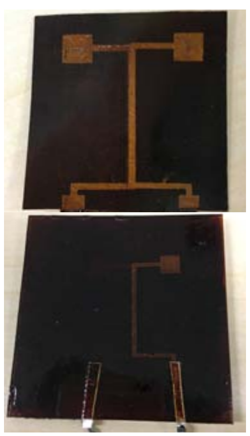

Figure 4: First prototypes: top) a prototype with a thin insulating layer, bottom) a prototype with a thick insulating layer.

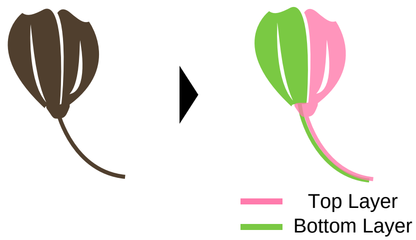

Figure 2: Example of a two-layer *urushi circuit*. Each layer has a touch electrode and wire.

Our study uses a multilayered circuit to construct a touch interface with its wiring hidden to retain beauty. A similar approach was used by Ta et al. [5] to create digital artwork; they hid wiring by connecting circuit patterns, which are printed with conductive ink on both sides of a paper, via holes. Tsuruta et al. [6] demonstrated a method to detect a touch on multiple electrodes printed on one side of a paper, which are connected with circuit patterns that are printed on the other side of the paper. By contrast, our study investigates the effects of the design of multilayered *urushi circuit* patterns based on touch detection.

Multilayered Urushi Circuit

Multilayering broadens the degree of freedom in arranging electrodes and wires and thus allows us to enrich the touch interface of lacquerware while maintaining its visual design. In our investigation, we first tested prototypes (first prototypes) consisting of two layers, each of which has a touch electrode and wire. Next, we tested four prototypes (second prototypes) that arranged all the touch electrodes on the top layer.

First prototypes

We first designed a touch interface with a single decoration (e.g., a flower with a stem) that can detect left and right touch positions and swipe gestures (Figure 2). Our idea to detect such rich touch vocabulary is to use multilayering to divide the decoration (Figure 2 left) into two parts (Figure 2 right), each of which is arranged in a layer (top and bottom layers) and has a touch electrode and wire. In this design, two wires are overlapped to form the stem of the flower. In addition, the covering thinly coating the *urushi* layer on the circuit pattern can maintain the visual design.

To test the above idea, we designed an *urushi circuit* to examine whether each touch electrode can detect a touch (Figure 3). This *urushi circuit* design has a touch electrode and wire in each layer. In addition, the wires connected to the touch electrodes were overlapped between the two layers. We fabricated an *urushi circuit* based on this design (Figure 4 top) according to the fabrication process described in [10]. In this process, the circuit pattern is printed by silkscreening with silver ink. The thickness of one urushi layer is approximately 30 μm. The cost of one *urushi circuit*, excluding the base material is approximately 6.6 USD (*urushi*: 3.5 USD, silver ink: 3.1 USD).

However, the two circuit patterns of the two layers were short-circuited due to an unevenness of the thin insulating *urushi* layer. Therefore, we constructed another *urushi circuit* (Figure 4 bottom) that has an insulating *urushi* layer thick enough to prevent a short-circuit by applying *urushi* twice. As a result, while short-circuiting was solved, this *urushi circuit* had a problem: the left and right electrodes appear different, as shown in the figure, given that the thickness of *urushi* on the two electrodes was different.

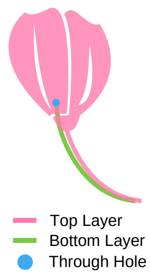

Figure 5: Example of a two layer *urushi circuit* that arranges all the touch electrodes on the top layer.

Second prototypes
To solve the first prototypes' problem, we adopted a different approach; we arranged all the touch electrodes on the top layer and used multilayering for wiring (Figure 5). To connect the electrodes on the top layer and wires on the bottom layer, we made through holes in the insulating *urushi* layer by using processing technology established by Myojin et al. [9]; it uses *urushi's* property where it can be decomposed by ultraviolet (UV) radiation.

We demonstrate the design of the *urushi circuits* (Figure 6); we designed four *urushi circuits* to investigate the effect of overlapping circuit patterns on touch detection:

- A There is no overlap between the left and right parts.
- B There is an overlap only between the wires of the two layers.
- C The wire of the bottom layer overlaps the touch electrode of the top layer.
- D The wire of the bottom layer overlaps both the wire and touch electrode of the top layer.

We fabricated the *urushi circuits* based on the design (Figure 7).

Evaluation of the Urushi Circuit

We tested whether the four *urushi circuits* work as touch interfaces. We connected a capacitance meter to the edges of the two wires of each circuit and recorded the sensor values when we touched various positions of the circuit. The capacitance meter was constructed using a Capacitive Sensing Library (CapSense) operating on Arduino. To touch the circuit, we used a capacitive stylus to prevent the contact area from changing. In this experiment, we touched the four positions of the circuit: a) touch electrode connected to the bottom layer wire, b) touch electrode connected to the

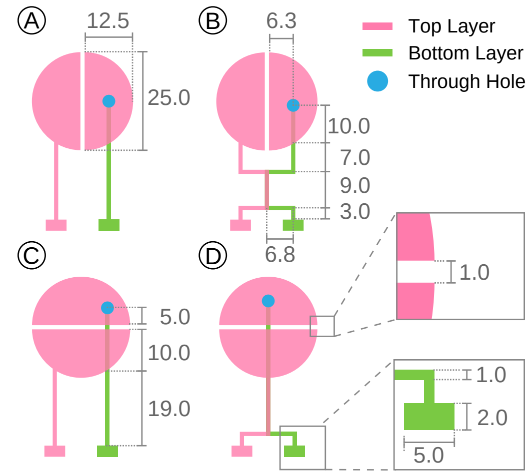

Figure 6: Design of the four *urushi circuits* and their dimensions (mm).

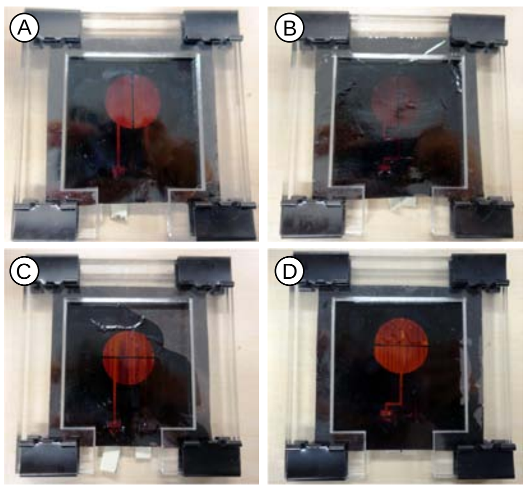

Figure 7: Four second prototypes.

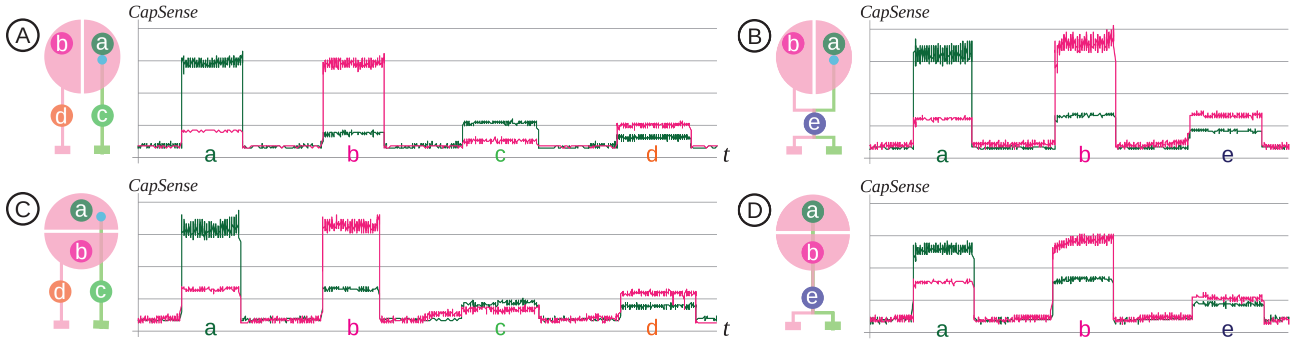

Figure 8: Capacitance waveforms measured by CapSense observed when the four *urushi circuits* were touched. The capacitances were measured at the edges of the two wires of each circuit. The a–d on the circuit design indicate touched positions: a) a touch electrode connected to the bottom layer wire, b) a touch electrode connected to the top layer wire, c) a bottom layer wire, d) a top layer wire, and e) overlapped wires. Each of a–d under the waveforms display the periods when each position of the circuits was touched.

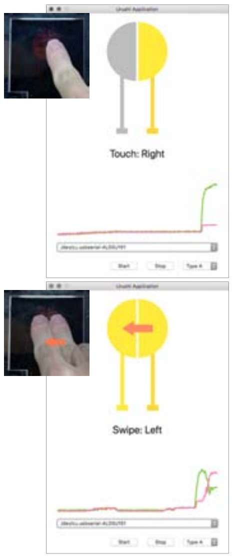

Figure 9: Test application detecting a touch on the right part (top) and left swipe (bottom).

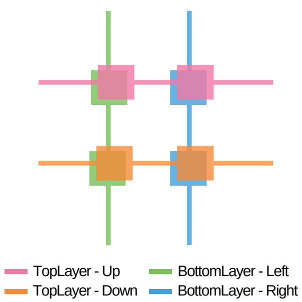

Figure 10: Design of a 2×2 grid circuit. Each of the four electrodes has two touch points which are overlapped in a grid pattern

top layer wire, c) bottom layer wire, d) top layer wire, and e) overlapped wires.

Figure 8 shows the waveforms of the sensor values measured with the capacitance meter. As the waveforms of a–b in Figures 8A-8D demonstrate, the sensor values of a touched electrode were larger than an untouched electrode. Moreover, the sensor values when a wire was touched (c–e) were smaller than the values when an electrode was touched (a–b). These results suggest that touch can be detected even if there is an overlap between the bottom layer wire and the upper layer wire, or between the bottom layer wire and the upper layer touch electrode.

Test Application

We developed a test application (Figure 9) that detects touches and swipe gestures and visualizes the results to demonstrate the potential of our second prototype as a touch interface. This application receives the sensor values from the capacitance meter and plots their waveforms. It also detects touches and swipe gestures using a threshold which was empirically defined. The swipe direction is judged from the order of touched electrodes.

Grid of Touch Electrodes

Projected capacitive touch sensing technology, which is used for two-dimensional touch sensing, consists of two layers of electrodes, which forms a grid. Given that this structure can be fabricated with a multilayered *urushi circuit*, it is possible to construct the surface of the lacquerware such that it detects the touched position. To test this, we designed a circuit that consists of a grid of two rows and two columns of electrodes with a multilayered *urushi circuit* (Figure 10). We arranged the two rows on the top layer and the two columns on the bottom layer. In this circuit, since each electrode has two touch points which are overlapped in a grid pattern, it is possible to detect four touch points.

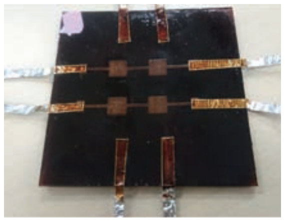

Figure 11: A 2×2 grid electrode.

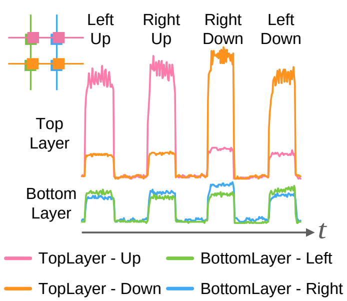

Figure 12: Four waveforms measured by CapSense when each point of a 2×2 grid circuit was touched.

Figure 13: *Urushi circuit* without coating the *urushi* layer.

We fabricated a *urushi circuit* based on this design (Figure 11).

Figure 12 displays the waveforms obtained by the capacitance meter when each touch point was touched. In this circuit, the waveform's amplitude of the bottom layer electrodes was smaller than those of the top layer. Nevertheless, the changes in the waveform of the electrodes corresponding to the touch point were larger than the others in each layer. For example, when the Left-Up touch point was touched, the changes in the BottomLayer-Left and TopLayer-Up waveforms were larger than the others. This result suggests that detecting four touch points with a 2×2 grid of electrodes could be possible.

Limitation
We believe that the *urushi circuit* can contribute to the field of media arts thanks to its elegant appearance. Designers can select colors by mixing *urushi* and pigment. However, designers cannot use pale colors, such as white and pale blue, because pure *urushi* is translucent brown. In addition, *urushi* cannot be applied to flexible objects. This is because *urushi* becomes stiff when dried. This means that when flexible objects to which *urushi* is applied are deformed, *urushi* will deteriorate and peel off.

Discussion and Future Work
In our investigation, we coated the circuit patterns with *urushi* (i.e., coating *urushi* layer in Figure 1). However, if the coating was thicker, the pattern was less visible, as shown in Figure 7B. To solve this problem, we fabricated the circuit with the circuit pattern exposed (Figure 13). As this circuit shows, if the designer wants to clearly display the pattern, it is effective not to coat the surface. On the other hand, the designer can hide the pattern by thickening the coating or by mixing it with paint. Therefore, the designer can select one of the two methods to design the appearance of the touch interface.

In addition, we demonstrated that the two-dimensional touch electrodes can be built with a multilayered *urushi circuit*. In the future, we plan to build a touch interface that detects touch positions more finely by constructing a finer grid circuit. In this interface, we will arrange the touch electrodes without overlaps based on our investigation of this paper. Specifically, we will use a diamond-shaped grid design, which is widely used in projected capacitive touch sensing technology.

Furthermore, *urushi* is often applied to non-flat surfaces (e.g., dishes). Therefore, we plan to investigate the effect of a *urushi circuit* that is fabricated on non-flat surfaces.

Conclusions
In this study, we investigated techniques to construct a touch interface that has the elegance and feel of the Japanese traditional material *urushi*. We focus on *makie*, which is the technique of drawing patterns on *urushi*, to incorporate touch electrodes into lacquerware as components of visual design. Furthermore, utilizing the feature that the circuit pattern can be multilayered, we demonstrated how the wires connected to touch electrodes can be hidden in a lower layer. Moreover, we demonstrated a multilayered *urushi circuit* with a grid of electrodes that realizes two-dimensional touch sensing.

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