Kirigami Keyboard: Inkjet Printable Paper Interface with Kirigami Structure Presenting Kinesthetic Feedback

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ABSTRACT

We propose a DIY process to produce a customized paper keyboard with kinesthetic feedback which interacts with a touch panel. The process was built on two techniques: kirigami and printable double-layered circuit, which can potentially improve extensibility and usability of various interfaces with paper substrate. First, kirigami structure provides kinesthetic sensation whose z-directional key stroke is comparable to that of traditional keyboard. In order to design appropriate stroke and reaction force to the keys, Rotational Erection System (RES) was adopted. Second, printable double-layered circuit allows users to adjust input layouts. This easy-to-customize keyboard can be of important innovation for those who have specific requirements for input devices.

CCS CONCEPTS

• **Human-centered computing** → **Haptic devices**.

KEYWORDS

Kirigami Structure; conductive inkjet printing; kinesthetic feedback; DIY.

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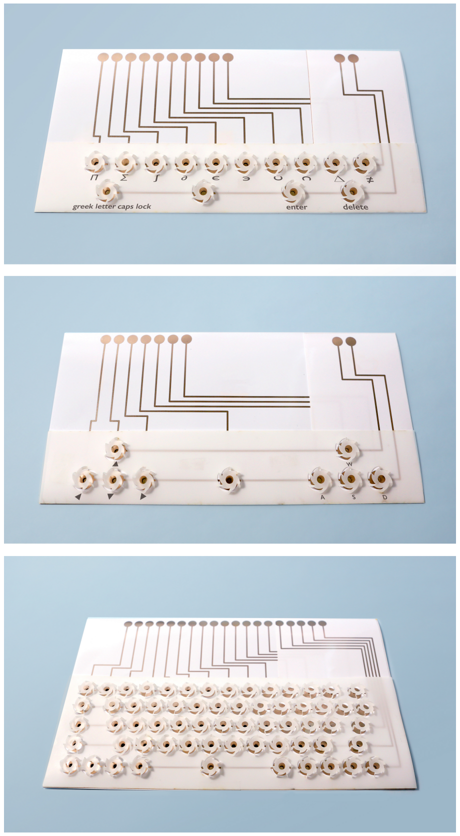

Figure 1: Three customized keyboards. Top: a mathematical keyboard. Middle: a left-handed gaming keyboard. Bottom: a full keyboard with 63 keys.

INTRODUCTION

Recently, many of our working and entertaining hours have been devoted to interacting with touch panels. From daily users to professionals (e.g., mathematician, designers) to those with disabilities, the demands for assistive keyboard inputs become more individualized. Despite various types of keyboards on the market, the requirement of diversity makes it difficult for users to be fully satisfied with pre-manufactured products. This issue let researchers propose several DIY-based extension interfaces which work as auxiliary input devices along with capacitive touch panels [2, 3, 6, 8, 10]. However, none of them achieved (1) z-directional kinesthetic feedback of widespread keyboards with "pushing down" sensation, (2) easy-to-prototype fabrication, and (3) customization/connection freedom to the touch screen at the same time.

We propose a process for producing a pressing-based keyboard that can be simply attached to a touch panel and easily customized for individual needs, by combining inkjet printed circuit along with kirigami structure. First, with kirigami technique, we designed folding and cutting patterns to construct 3D shaped keys from 2D sheets. Second, with conductive ink, we developed a printable double-layered circuit attached to the edge of a touch panel, which transfers the pressing input from the keyboard to a touch panel. This method enables the design freedom of keyboard interface in terms of key layouts, key composition, and key functions. As demonstration, we prototyped three coustomized keyboards for mathematics, games, and laptop-like tasks in Figure 1. Kirigami and conductive inkjet printing technique is highly accessible and cheap, so this process achieves reusable keyboard, whose usability is similar to that of pre-manufactured keyboards.

RELATED WORK

Extension of Capacitive Touch

Many researchers have tried to extend capacitive touch interfaces with physical handles, such as buttons [2], knobs [11], and sliders [1]. All of these approaches are based on the principle that capacitive coupling between a user and a touch panel can be mediated with an electrically conductive object. Other researchers developed inkjet printed conductive patterns to augment capacitive touch panels, such as ExtensionSticker [8], CapacitiveMarker [6], and trackpad for virtual reality application [3].

Customizable Button with Clicking Feedback

Klamka et al. Pushable [10] proposed the method to prototype buttons with clicking effects, using embossing membranes made by manual assembly or automatic pushing with the nozzle of a 3D

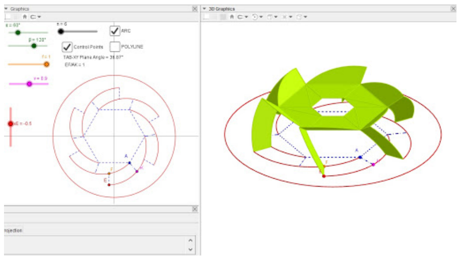

Figure 2: Parametric design of a RES-based button

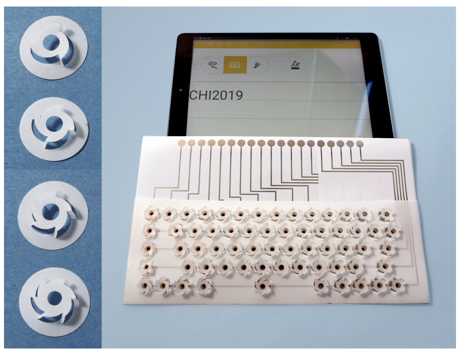

Figure 3: RES-based buttons after cut with an XY knife cutter

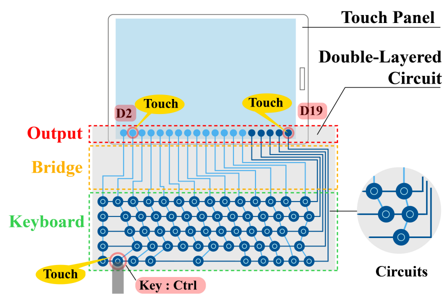

Figure 4: A double-layered circuit attached to the touch panel

printer. However, their method comes with several human labors and longer takt time, which needs improvement for easy fabrication.

Kirigami

Kirigami is an art of making 2D/3D shapes by cutting paper, and many researchers have investigated the usage of kirigami structures, including a skin for a snake-like robot [14] or tall 3D structures from a flat paper [12]. These patterns can realize 3D structure out of 2D sheets, with accessible tools such as a laser cutter, an XY knife cutter, or simply a hand knife.

Inkjet Printable Conductive Circuit

Conductive circuit with off-the-shelf inkjet printer enables fast, low-cost fabrication of circuit without any post-processing like heat sintering [9]. This fabrication technique has been widely applied to many components, such as sensors [5], actuators [13], and touch keys [4].

KIRIGAMI KEYBOARD

Kirigami Structure

The kinesthetic feedback with proper push stroke and reaction force is an indispensable factor for a comfortable keyboard. We proposed a method to design 3D shaped key by using the kirigami technique. Rotational Erection System (RES) [12] is a technique to construct a 3D structure by folding and rotating the 2D sheets such as papers or metal sheets with rotationally symmetrical folding and cutting pattern. In addition to its 3D shapes, it is possible to control the elasticity in lifting direction by adjusting the design parameters of the original 2D pattern. Based on the geometrical relationship between the cutting pattern and the 3D shape in RES, the design software was developed [12]. We examined various RES design by this software and found patterns that have proper elasticity for a push button. Figure 2 shows the hexagonal RES which we used in the kirigami keyboard. This pattern has bistable property and is stabilized in lifted shape. The hole inside of each key was designed for user's fingers to contact the double-layered circuit in order to transfer the touch input to the touch panel. Finally, an array of RESs (as shown in Figure 3) was arranged to realize a desired shape of the keyboard, presenting kinesthetic feedback.

Double-layered Circuits

Inspired by Clip-on Gadget [2] and ExtensionSticker [8], our method simply attaches the paper keyboard without reading the resistance value, which transfers touch inputs from the printed circuit to a touch panel. However, there is a practical problem if try to put a large number of keys on the keyboard. When we use one conductive circular disk as a key connected to one conductive circular

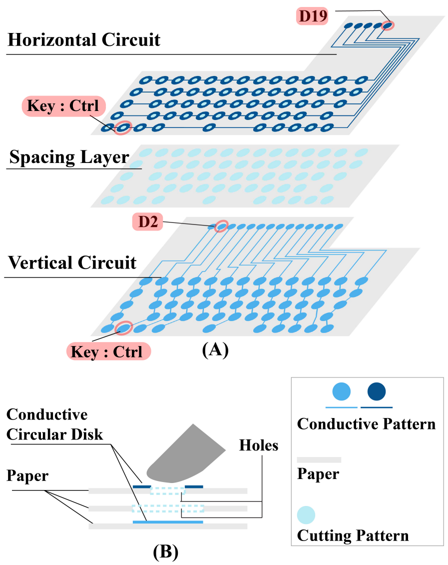

Figure 5: Schematics of circuit layers. (A) a perspective view and (B) a cross sectional view

disk on the touch panel, too much space would be blocked at the side of touch panel. Letting n be the total number of keys, the number of conductive circular disks needed is n and the spatial complexity is also $O(n)$. This means it gets linearly difficult to arrange wiring from circuit to the touch panel as the number of keys increase.

To solve this issue, we adopted a double-layered matrix as shown in Figure 4. In this mechanism, one touch input in the paper keyboard activates two points on a touch panel, which reduces space complexity of wiring from $O(n)$ to $O(n^{\frac{1}{2}})$, and thus leads to the smaller total contact area needed on the touch panel. It consists of three sheets pasted together: a horizontal circuit layer, a spacing layer, and a vertical circuit layer as shown in Figure 5A. For example, if you push a Ctrl key in Figure 5A, both D19 in the horizontal circuit layer and D2 in the vertical circuit layer are activated. The 0.5 mm thick spacing layer (as shown in Figure 5B) was designed to reduce the noise between the two circuits.

Discussion

To examine the feasibility of double-layered circuit, we calculated the contact area needed on the touch panel by using a 15-inch MacBook keyboard layout (64 keys) and a typical Android system 9.7-inch tablet ASUS ZenPad Z10 (resolution 2048 × 1536). Previous study [7] suggested designing the contacting area of circular disks with approximately 6 mm to 8 mm diameter. If we use a single-layered circuit (one conductive circular disk connected to one conductive circular disk on a touch panel), at least 6 mm × 64 = 384 mm to 8 mm × 64 = 521 mm contacting space is required. On the other hand, by using double-layered circuit (one conductive circular disk connected to two conductive circular disks on a touch panel), it enables to user to make 64 keys keyboard by using 19 disks on the screen, occupying only 6 mm × 19 = 114 mm on the long edge of a touchscreen.

CONCLUSION AND FUTURE WORK

We presented a simple DIY process of a customizable keyboard which can extend capacitive touch panels. The key innovations are followings: (1) 3D shaped keys with kinesthetic feedback are constructed by folding and cutting 2D sheets with RES pattern; (2) a printable double-layered circuit provides the keyboard with more design freedom and extensibility than single-layered design. In the near future, we will explore the possibility of this process by designing various types of comfortable elastic sensation and keyboard layouts that meet the various needs of users.

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