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

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ABSTRACT

We propose a DIY process to produce customized paper keyboards with kinesthetic feedback that interact with touchscreens. The process is built using two techniques: kirigami and printable double-layered circuits. Our goal is to improve the extensibility and usability of various interfaces made with 2D paper substrates. First, Our kirigami structures provide kinesthetic sensations whose z-directional key stroke is comparable to that of traditional keyboards. In order to design keys with appropriate stroke and reaction force, we adopted the Rotational Erection System (RES). Second, printable double-layered circuits allow users to easily adjust input layouts. This easy-to-customize keyboard can be especially useful for those who have specific requirements for input devices.

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CCS CONCEPTS

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

KEYWORDS

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

* The first two authors contributed equally to this work.

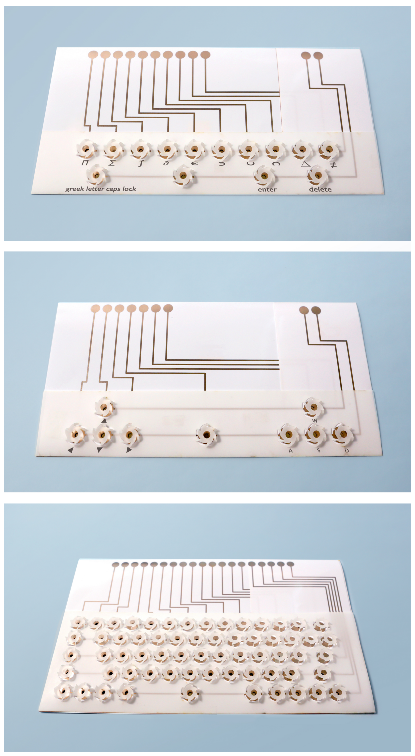

Figure 1: Three customized keyboards. Top: a mathematical keyboard. Middle: a left-handed gaming keyboard. Bottom: a full keyboard with 63 keys.

INTRODUCTION

More and more our working and leisure hours are devoted to interacting with touchscreens. From everyday users to professionals (e.g., mathematician, designers) to those with disabilities, the demands for assistive keyboard inputs have become more individualized. Despite various types of keyboards on the market, the diversity of requirements makes it difficult for users to be fully satisfied with pre-manufactured products. This issue has inspired researchers to 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 have achieved (1) the z-directional kinesthetic feedback - "pushing down" sensation - of common keyboards, (2) easy-to-prototype fabrication, and (3) high customizability.

By combining inkjet printed circuits with kirigami structures, we introduce a process for producing a pressing-based keyboard that can be easily attached to a touchscreen and customized for individual needs. First, with the 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 that attaches to the edge of a touchscreen, which transfers the pressing input from the kirigami keyboard to the touchscreen. This method gives users the freedom to design keyboard interfaces in terms of key layouts, key composition, and key functions. To demonstrate, we prototyped three customized keyboards for mathematics, games, and laptop-like tasks in Figure 1. Kirigami and conductive inkjet printing techniques are highly accessible and cheap, so this process achieves an easy-to-fabricate and reusable keyboard, whose usability is similar to that of massmanufactured keyboards.

RELATED WORK

Extension of Capacitive Touch

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

Customizable Button with Clicking Feedback

In Pushables [10], Klamka et al. proposed prototyping buttons with clicking effects, using embossed metal caps that are laminated to printed circuits to produce custom pushbutton interfaces. However, their method requires much manual labor and time to construct.

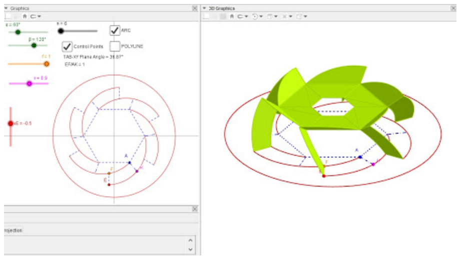

Figure 2: Parametric design of a RES-based button.

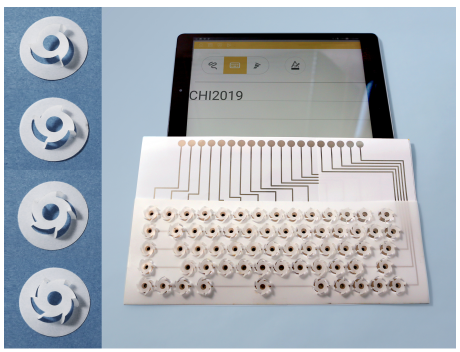

Figure 3: RES-based buttons after cut with an XY knife cutter.

Kirigami

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

Inkjet Printable Conductive Circuit

Making conductive circuits with off-the-shelf inkjet printing enables fast, low-cost fabrication of circuits without post-processing like heat sintering [9]. This fabrication technique has been widely applied to create 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 propose a simple method to design 3D shaped keys by using kirigami. Rotational Erection System (RES) [12] is a technique to construct 3D structures by folding and rotating the 2D sheets, such as paper or metal sheets, with rotationally symmetrical folding and cutting patterns. In addition to its 3D shape, it is possible to control the elasticity in lift by adjusting the design parameters of the original 2D cut and fold pattern. The design software was developed [12] based on the geometric relationship between the cutting pattern and the 3D shape in RES. We examined various RES designs using this software and found patterns that produce the proper elasticity for a push button. Figure 2 shows the hexagonal RES which we used in the kirigami keyboard. This pattern is bistable and is stabilized in the lifted configuration. A hole inside each key enables users' fingers to contact the double-layered circuit in order to transfer touch input to the touchscreen. Finally, an array of RESs (as shown in Figure 3) was arranged to create a desired shape and kinesthetic feedback of the keyboard.

Double-layered Circuits

Inspired by Clip-on Gadget [2] and ExtensionSticker [8], our method simply attaches the paper keyboard directly to the touchscreen, which transfers touch inputs from the printed circuit to the touchscreen. However, there is a practical problem: How to put a large number of keys on the keyboard with limited touchscreen space. If we use one conductive circular disk as a key to connect to one conductive circular disk on the touchscreen, we block too much space on the screen. Letting n be the total number of keys, the number of conductive circular disks needed on the touch screen is n and

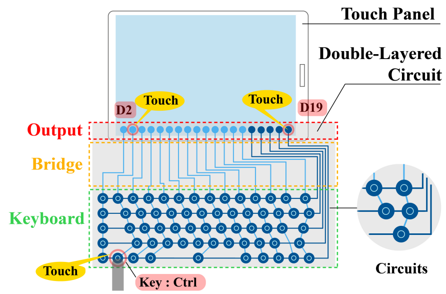

Figure 4: A double-layered circuit attached to the touch panel

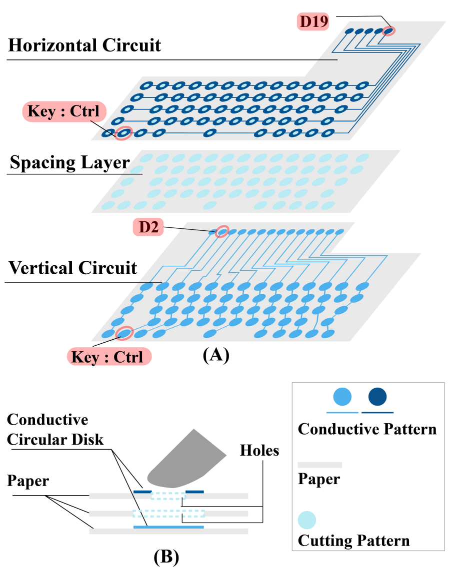

Figure 5: Schematics of circuit layers. (A) a perspective view and (B) a cross sectional view

the spatial complexity is $O(n)$. This means the difficulty in arranging wiring from the circuit to the touchscreen scales linearly with the increasing number of keys.

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 the 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 circuit layers.

Discussion

To examine the feasibility of a double-layered circuit to produce the desired number of keys, we calculated the contact area needed on the touchscreen 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). A previous study [7] recommends designing the contact area of circular disks to be approximately 6 mm to 8 mm in diameter. If we use a single-layered circuit (one conductive circular disk connected to one conductive circular area on the touchscreen, 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 present a simple DIY process for designing and fabricating a customizable keyboard which can extend the interactive capabilities of capacitive touchscreens. Our key innovations are: (1) 3D shaped keys with kinesthetic feedback constructed by folding and cutting 2D sheets with the RES pattern; (2) printable double-layered circuits providing the keyboard with more design freedom and extensibility than single-layered designs. In future work, we will continue to explore the possibilities of this process by designing varying types of elastic sensations and keyboard layouts to meet the needs of diverse user communities.

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