Investigating Reaction Accuracy of Extended Touchscreen with Conductive Ink for Mobile Virtual Piano

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ABSTRACT

Various methods have been researched to extend the interaction spaces around mobile devices. The method of using conductive ink extends touch interaction space using a sheet with a pattern of conductive ink, which is attached to a capacitive touchscreen. However, the extended area of the interaction space with this method depends on the size of the sheet on which the conductive ink can be printed. We propose a method of connecting sheets using conductive aluminum foil tape. As a test system and an application of this method, we fabricated a mobile virtual piano system with a two-octave keyboard and evaluated the reaction accuracy.

CCS CONCEPTS

• **Human-centered computing** → **Touch screens**.

KEYWORDS

conductive tape, capacitive touchscreen, interaction space

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1 INTRODUCTION

Various methods have been researched to extend the interaction spaces around mobile devices; examples include the ones using vibration acoustic sensors [6], built-in microphones [5], and conductive ink [1, 4]. In particular, the latter method is attractive. It extends touch interaction space using a sheet with a pattern of conductive ink, which is attached to a capacitive touchscreen. It requires no additional electronic device and thus is easier to use than other methods and it is low cost because conductive ink in a ballpoint pen or a home inkjet printer facilitates forming a pattern on paper [4]. However, the extended area of the interaction space with this method depends on the size of the sheet on which the conductive ink can be printed; when using a commercially available sheet, the extended area is limited to A4 size (210 mm × 297 mm).

Our final goal is to detect touches with high accuracy to extend the interaction space even when multiple sheets are connected and realize applications such as a mobile virtual 88-key piano. In this paper, we tested connecting sheets using conductive aluminum foil tape. Specifically, we fabricated a two-octave mobile virtual piano using two sheets as a test system to investigate the touch reaction accuracy.

2 TEST SYSTEM: MOBILE VIRTUAL PIANO

As a test system that uses connected multiple sheets, we fabricated a mobile virtual piano system with a two-octave keyboard with C4–B5 keys (Fig. 1).

2.1 Structure

Fig. 2 shows the structure of our mobile virtual piano system. The system has simple software that runs on a tablet computer with a capacitive touchscreen (iPad Pro; 12.9-inch 3rd-generation iPadOS 14.2; Apple) and two sheets (NB-TP-3GU100; Mitsubishi Paper Mills) with conductive ink (NBSIJ-MU01; Mitsubishi Paper Mills) printed using an inkjet printer (PX-S160T; Epson). The software displays 24 buttons on the touchscreen. Each button is assigned a piano sound and plays the sound when tapped. On each sheet, the pattern of piano keys is printed using conductive ink. We printed the pattern on the same sheet twice to decrease resistance for improving recognition accuracy [2]. The printed pattern consists of 3 kinds of portions (Fig. 2): an *input portion* that is a piano key, an *output portion* that is attached to the touchscreen for generating touch event, and a *connection portion* that connects an *input portion* to its corresponding *output portion*. The *output portions* are attached to the touchscreen using non-conductive double-sided adhesive tape (NW-10, thickness 0.09 mm; Nichiban) to cover the buttons on the touchscreen. For the connection between the sheets, we used 10.0 mm wide aluminum foil tape (791-10X20; Teraoka Seisakusho). When a user touches a key printed on the sheet, the capacitance of the corresponding *output portion* changes. As a result, a touch event occurs on the touchscreen. Then, the software plays the piano sound according to the touched key.

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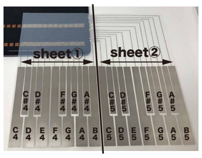

Figure 1: The test system: a two-octave keyboard with C4–B5 keys.

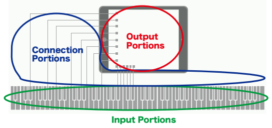

Figure 2: The structure of our mobile virtual piano system.

To determine if touch reaction accuracy depended on whether the *connection portions* crossed a sheet boundary, we arranged the *connection portions* not to cross the boundary for one octave (C4–B4; *non-crossed keys*) and to cross the boundary for the other octave (C5–B5; *crossed keys*).

2.2 Electrode size and arrangement

We performed a preliminary survey to determine a pattern that responded well to touch. The survey showed that the larger the size of a square-shaped *output portion* is, the better the reaction is. To ensure high accuracy, it was necessary to have a size of 6.0 mm or more on each side; the width of the *connection portion* reacted 100% when it was 0.5 mm, and the reaction became worse as it became wider. Based on this result, we determined the size of each portion. To place 88 buttons on the touchscreen of the iPad Pro, each *output portion* was an 8.0 mm square. The width of each *connection portion* was 0.5 mm.

In addtion, the size of each *input portion* was smaller than a real size of the piano key to place the gap between two adjacent keys (2.0 mm). The aluminum foil tape was cut as narrowly as possible (approximately 2.5 mm) so that no touch event would occur under the tape.

3 USER STUDY

We performed a user study to investigate the touch reaction accuracy.

3.1 Task and Procedure

The participants were 3 students (one female, all aged 22 years) in our laboratory. Each participant performed a task in which they touch each key 5 times with the index finger of the right hand at 4 different tempos, 60, 80, 100, and 120 beats per minute (BPM), following a metronome. The tempos were presented in ascending order (i.e., first in BPM=60, then in BPM=80). To prevent mistouching due to finger movement, a short pause was inserted before moving on to the next key. Participants began to touch the next key at their own timing following the metronome. A 2–3 minute break was taken when the tempo was changed. To be familiar with the way to use the system and the sound it produces, participants were allowed up to 5 min of free practice before starting the task.

The iPad Pro was connected to an AC adaptor during the experiment to stably discriminate between touch and non-touch states [3].

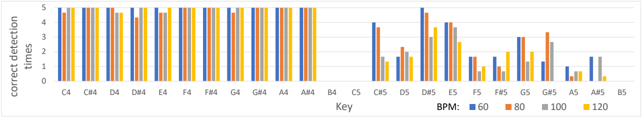

Figure 3: The average number of times sounds were played correctly for each key (C4–B4: *non-crossed keys*, C5–B5: *crossed keys*).

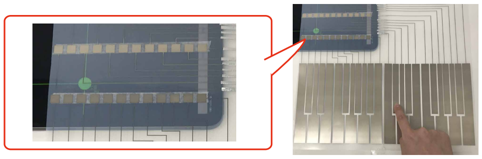

Figure 4: The location where the touch event occurred.

3.2 Result

Fig. 3 shows the average number of correct responses for each of the 24 keys (i.e., two octaves). All *non-crossed keys* except B4 responded near-perfectly for all participants at all tempos (average = 4.9 times). B4 did not respond at all. Of the crossed keys, C5 and B5 did not respond at all. In addition, the overall *crossed keys* response accuracy was lower than that of the *non-crossed keys*.

3.3 Additional Investigation

To explore why *crossed keys* responded poorly, we used MultiTouch Visualizer[1] to investigate where touch events occurred. As a result, we observed that touch events sometimes occurred at the point where a *connection portion* was bent at a right angle (Fig. 4).

4 DISCUSSION

The user study showed that the *non-crossed keys* responded almost always responded even at the fastest tempo. In contrast, the touch reaction accuracy of the *crossed keys* was low. As the additional investigation shows, one reason for the low accuracy would be that touch events sometimes occurred at the point where the *connection portion* was bent at a right angle. To solve the above problem, it is necessary to ensure that touch events occur reliably at the location of the buttons. Possible solutions would be to place a button at the location where the *connection portion* is bent or to smoothly bend the *connection portion* like an arc.

Also, the keys with buttons near the edge of the screen (i.e., B4 and B5) were not responsive. To solve this problem, we plan to redesign the pattern to place buttons as closer to the center of the screen as possible.

5 CONCLUSIONS

We investigated a method of connecting a commercially available A4 size sheet to further extend the interaction space around a mobile device. As a test system and an application of this method, we fabricated a mobile virtual piano system with a two-octave keyboard and evaluated the reaction accuracy. As a result of connecting

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[1] https://apps.apple.com/jp/app/multitouch-visualizer/id376335100 (Accessed: 2021-04-20)

using conductive aluminum foil tape, the reaction accuracy was lower than that of a key whose *connection portion* does not cross any boundary of sheets, while the reaction was seen and the operating area could be further extended. Also, the additional investigation has revealed possible improvement in the current design of the pattern. We will modify the layout of the printed pattern to improve the accuracy of the response.

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