Is It Gropable? – Assessing the Impact of Mobility on Textile Interfaces

Nicholas Komor, Scott Gilliland, James Clawson, Manish Bhardwaj, Mayank Garg, Clint Zeagler, and Thad Starner
GVU Center
Georgia Institute of Technology
Atlanta, Georgia USA
{*nicholaskomor,scott.gilliland,jamer,manishbhardwaj,mayankgarg,clintzeagler, thad*} *@gatech.edu*

***Abstract*—In a mobile environment, the visual attention a person can devote to a computer is often limited. In such situations, a manual interface should be "gropable," that is, the user should be able to access and use the interface with little to no visual attention. We compare stationary and mobile input on two embroidered textile interfaces; a single touch three button interface and a multitouch four button interface that is activated by pressing two buttons at the same time. 16 participants completed 480 trials while walking a path and sitting. While multitouch increases the expressiveness of gestures that can be performed, our user study only shows a slight, not statistically significant, increase in accuracy and an understandable decrease in speed for simple selection tasks.**

I. Introduction

Early research on electronic textiles created prototypes to explore what might be possible in the fledgling field [6]–[8]. Research groups continue to develop new sensors and interfaces and test their manufacturability and washability [4], [5]. Buechley has even used electronic textile prototyping as a vehicle for teaching electronics to high school students [2]. However, little systematic usability evaluation has been reported on textiles as interfaces. Such evaluation can help direct sensor and interface design.

For example, a recent qualitative study by Holleis *et al.* [3] examined capacitive sensing with textiles and recommends interface designers focus on the

> **Need to tackle the fear of accidentally initiated commands:** ... users want to be sure that they don't accidentally operate a button when touching it by accident. On the other hand, longer required touch time when deliberately operating often led to frustration as there is no immediate reaction. Mechanisms that provide immediate response and also have a key lock function need to be developed.

This observation matches our own. Given our focus on mobility, we are particularly interested in "gropability" — the ability of the user to access and control a textile interface while visually distracted or "on-the-go". Gropability implies that the system can recognize intentional interactions while rejecting unintentional "touches" caused by the bumps and self-shorting that is typical of mobile interfaces. In this paper, we report a formal quantitative user study that compares our multi-touch textile interaction method to a more typical capacitive textile interface design.

II. Prototypes

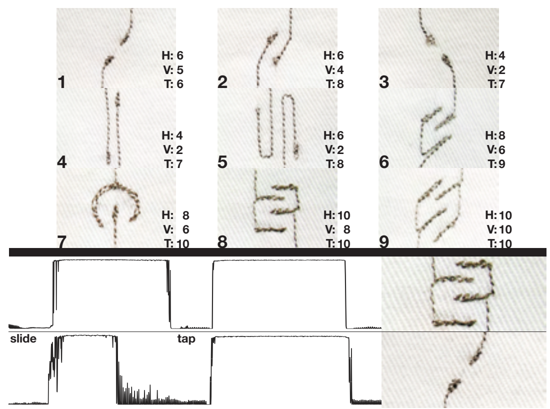

Figure 1. Top: Nine embroidered buttons tested. H, V, and T indicate the number of Horizontal slides, Vertical slides, and Taps of a bare finger detected for each design (out of a possible 10). Bottom: Oscilloscope traces showing button pressing detection.

Raised embroidery can help tactilely (rather than visually) guide the user to buttons. Initially, we sensed button presses through a resistive circuit design using a Darlington Pair to get sufficient sensitivity. We explored several embroidery designs for best sensing finger contact. Figure 1 shows nine of these designs. We performed a pilot study on the sensitivity of these designs to ten bare finger taps, ten slides horizontally on to the gap, and ten slides vertically on to the gap.

In general, designs with interleaved "fingers," such as the bottom three designs, recognized interactions significantly better than single fingered designs, such as the top three. Single finger designs averaged 15 errors (of 30 interactions). The bottom right design performed best, with no errors. However, as horizontal and vertical stitches were more repeatable on our embroidery machine, we opted for the middle bottom row pattern which had only two errors, for our prototype. The bottom oscilloscope trace shows typical interactions with the single finger designs, and the top trace shows the more robust signal received from our selected design. Received signals became weaker, but still distinct, the longer the user interacted with the prototypes, presumably because moisture on the finger was absorbed by the fabric. Upon further experimentation, we switched to a hybrid capacitive/resistive approach for sensing.

Based on a four button design, we created a multitouch interface where the user could use a "pinch" interaction now common on consumer devices. One larger button, which we term the "anchorpad," is designed to anchor the user's thumb during motion and allow quick and accurate interaction with the three smaller buttons (see Figure 2). The user can grope for the anchorpad, trigger it with his thumb, and then slide his index finger over the other three buttons, landing on the one for his intended selection. Upon release, that small button is selected. Note that a multitouch interface allows quite an expressive array of interactions. A user can perform a "inverse pinch" started from the anchor pad or can perform a normal pinch with the index finger starting from the opposite side. He could start at the anchorpad and then chord using three fingers. By adding anchorpad at the opposite end, the user could start with his thumb at the top anchorpad, anchor his index finger on the middle small button, and then use his thumb and little finger as if they are on the opposite sides of a rocker switch. Our hypothesis was that such anchoring interfaces could result in fewer false button press detections and create systems that were more gropable, especially when mobile.

In order to test this hypothesis, we compared our simplest multitouch interaction to a three button single touch interface. We built a prototype system that included the interfaces sewn into a shoulder pack strap. In addition to the interfaces, our system included a pair of headphones for delivering audio prompts, and a Sony Vaio palmtop carried in the bag for data collection (see Figure 3). To make a selection on the single touch interface, the user feels for the buttons and simply holds the desired one. Because the user accidentally hits several buttons before finding the appropriate one, the system only registers a button press when the user touches it, and it alone, for more than two seconds. Our system plays an audio "beep" when it registers the button press. The user makes a selection on our four button multitouch interface in much the same way. The user simply presses the desired button while pressing and holding the anchor pad at the same time. In future iterations, the use of multitouch can help disambiguate accidental from intentional presses, though for the purpose of this study we still rely on a two second dwell time to register a successful button press.

III. Study Design

The study was structured as a 2 x 2 within-subjects design. We presented the participants two mobile conditions (seated and walking) and two embroidered tactile fabric interfaces (one with an anchor pad and one without). With each trial lasting approximately 10 minutes, the entirety of the study took about one hour to complete. The sessions were separated by a brief two minute break to enable the participants to rest and prepare for the next trial. Each trial consisted of 30 selections (ten for each position). The order of conditions was randomized across participants as was the order of the 30 selections within a trial. Our participants were compensated at a rate or $10/hour rounded to the nearest half hour for their time.

We recruited 16 individuals to participate in our study. Our participants ranged in ages from 18 to 36 with an average age of 23. Seven participants were female and five were left–handed.

Before the first session, each participant was given verbal instructions explaining the task and goals of the experiment. The researchers described the two different prototypes and the mobile conditions to the participants. The participants were instructed to respond as quickly and as accurately as possible to the voice commands which indicated which position to touch. The participants were then led through a series of training exercises in which they interacted twice with each target on both the three-button and four-button prototype. They performed this training exercise while seated and again while mobile.

Using previous studies as a guide [1], [9], our participants were instructed to walk at a normal pace around a track constructed in our laboratory (see Figure 4). The track was approximately 25.8 meters long and was denoted with flags hanging from the ceiling with the tips 0.75 meters apart. Each flag was hung so the tip was approximately 1.6 meters above the floor. We chose to use flags to ensure

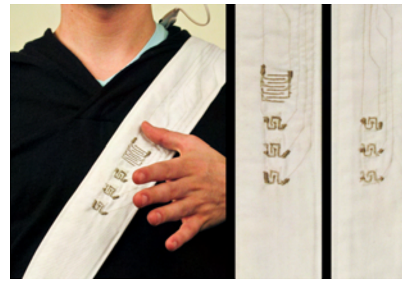

Figure 2. Top: 3 and 4-button prototypes. Bottom: 4-button multitouch interface sewn into a messenger bag strap and worn across the body.

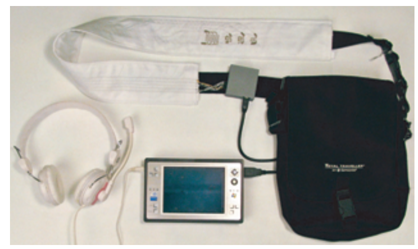

Figure 3. Our prototype system comprised the interfaces sewn into a shoulder pack strap, a pair of headphones for delivering audio prompts, and a Sony Vaio palmtop carried in the bag for data collection.

that participants were engaged in a head-up task enforcing the intended nature of our study. Had the participants been following a path laid out on the ground, a head-down condition would have ensued and participants would have direct visual contact with the interface.

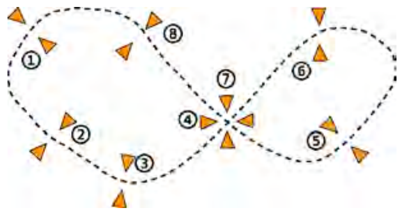

Figure 4. Participants walked the path starting at flag 1 and proceeded clockwise around the 25.8m course.

A. Equipment and Software

Our experimental software was implemented in Python on a Sony Vaio palmtop running the GNU/Linux operating system. During each condition, the operation of the software was the same. At random intervals between 10 and 20 seconds (selected from a uniform random distribution), the software generated a synthetic audio voice prompt instructing the participant to touch either the "top," "middle," or "bottom" button.

To respond to the prompt, participants groped the interface, located the buttons, and attempted to press the button indicated by the alert. If the participants were in a 3-button condition, they simply had to press and hold the indicated button. If they were in a 4-button condition, they needed to press and hold both the "anchor" pad and the indicated button. The software waited for the user to press a button for 2 seconds and played an audio tone through the headset. In the event that the participant was not successful, the software would timeout a trial at the end of six seconds and play the same tone. At this point the trial was complete and a timer was set to generate the next voice prompt. The software logged the timestamps of each prompt, as well as every touch event that occurred during a trial. No feedback was given to the participants to indicate if a trial was a success or a failure. The sound simply indicated the conclusion of one trial and the beginning of the next.

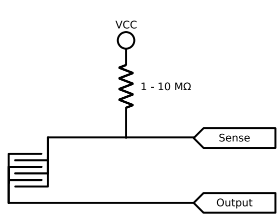

Figure 5. Our capacitive sensing circuit allowing a microcontroller to sense the leakage resistance across a textile pad.

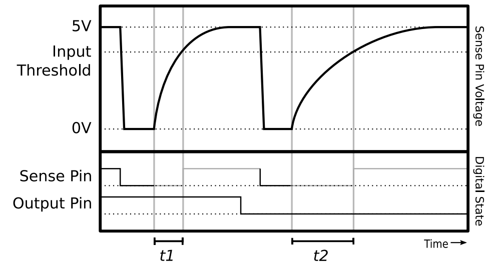

Figure 6. A timing diagram of how a microcontroller can sense the leakage resistance across a touch pad. Discharging the capacitance of the pad twice, once with without leakage current and once with, yields a measurement of the leakage current through a fingertip.

Mobile Condition	Interface	Mean(SD)	Min	Max
Stationary	3-position	23.06(5.18)	12	30
Stationary	4-position	23.50(5.68)	15	30
Mobile	3-position	25.69(4.42)	14	30
Mobile	4-position	26.38(4.29)	16	30

Table I
THE NUMBER OF CORRECT BUTTON PRESSES PER CONDITION AS WELL AS THE MINIMUM AND MAXIMUM NUMBER OF CORRECT PRESSES PER CONDITION. N=480.

Our sensing hardware consisted of an Atmel Atmega168 microcontroller. The Atmega sensed by detecting leakage current across the textile finger pads (see Figure 5). This was done by charging up the capacitor formed between ground and one side of the touch pad, examining the time taken for it to discharge through a known resistor. By driving the other side of the touch pad to ground or power, the leakage current through a finger would vary the time needed for the capacitor to discharge. Thus, by measuring the discharge time twice, we can use the difference in times to determine the leaked current through the fingertip (see Figure 6). Any constant capacitance in the pad gets canceled out. Once the Atmega had determined how much current was able to leak through the touch pad, it then relayed this value to the palmtop computer via a USB-to-RS232 converter, where the software could process the data.

IV. RESULTS

The 16 participants engaged in 480 total trials (30 trials per participant or 10 trials per button per participant) resulting in 80 trials per button on each interface. Our participants on average pressed the correct button on either the 3-button or 4-button interface over 23 times while stationary and over 25 times while mobile (see Table I). We found no statistically significant difference in the number of correct button presses between the prototypes while stationary or while mobile. The time required to press the correct pad was longer for the 4-button interface for both the mobile and stationary situation ($p < 0.01$). Figure 7 shows the dwell time needed to ensure acceptable selection accuracy in the various conditions.

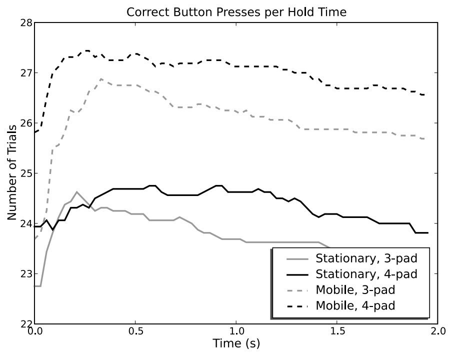

Figure 7. Hold time versus selection accuracy (30 trials)

Mobile Condition	Interface	Mean(SD)
Stationary	3-position	4.6(1.1)
Stationary	4-position	5.1(1.1)
Mobile	3-position	4.3(1.0)
Mobile	4-position	4.5(1.1)

Table II
TIME FROM AUDIO PROMPT UNTIL CORRECT ANSWER (OR 6 SECONDS IF WRONG PAD CHOSED).

V. DISCUSSION

Our 4-button prototype had slightly better accuracy than the normal 3-button design but required more time for selection. However, examining Figure 7 reveals that the 4-button design requires less hold time than the 3-button design when mobile to get the maximum accuracy. Interestingly, accuracies fall with longer hold times for all conditions, but the 4-button interface accuracy decays less than the 3-button. Accuracy seems to peak at approximately a third of a second dwell time for all conditions. This value may prove significant in improving future designs.

One challenge that arrises when evaluating a fabric interface is the on-body placement of such an interface. Designing a wearable interface such that it is easily worn by participants of both genders, of any shape or size, in a manner that is ecologically valid is a non-trivial endeavor. For example, we initially designed interaction techniques for an interface sewn into the sleeve of a shirt. Situating the interface on a user's shoulder affords a completely different set of interaction techniques compared to an interface placed across a user's chest or on a user's thigh. Designing a sleeve that can be easily worn by participants was considered though we eventually evaluated our interfaces on the strap of a messenger bag. Though this decision made it easy for participants to wear and switch between the two interfaces used in the study, it resulted in some unexpected interactions. As mentioned above, we anticipated that participants would interact with our four-button interface by placing their thumb on the anchorpad and groping for the indicated button with their pointer finger. However, in conducting the study we observed several different modes of interaction that were afforded by the placement of our interface across the body which would not have been possible had the interface been placed on the shoulder. For example, several of our participants interacted with the shoulder strap interface by placing their thumb on the back of the strap and using their index finger to ground the interaction by placing it on the anchor pad.

VI. CONCLUSION AND FUTURE WORK

Our results suggest that a multitouch system, while taking slightly longer to use, could lead to a more expressive and accurate textile interface for mobile situations. We have discovered that a hold time of approximately a third a second seems to be optimal for achieving the highest accuracies for our textile buttons. Future work includes experimenting with button placement and experimenting with more sophisticated uses of the interface as well as more sophisticated interface designs.

VII. ACKNOWLEDGEMENTS

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