BackC&P: Augmenting Copy and Paste Operations on Mobile Touch Devices Through Back-of-device Interaction

Liang Chen[1]
School of Software Engineering, Chengdu University of Information Technology, Chengdu, China[1]
Sichuan Province Engineering Technology Research Center of Support Software of Informatization Application, Chengdu, China[1]

***Abstract*—As more and more complex applications, e.g. photo editing software and slideshow editing software, can be used on mobile touch devices, some simple operations, such as copying and pasting, are used more frequently by ordinary mobile users. However, the existing touch techniques are far from perfectly supporting these simple operations on mobile devices. In this paper, a new interactive technique BackC&P, which takes advantage of back-of-device touch input to augment copy and paste operations on mobile devices, is presented. The results of a user study that evaluated the usability of BackC&P are also presented. The findings indicate that BackC&P was about twice as fast as the currently used technique on mobile touch devices when used to complete the copy-and-paste tasks, with no significant decrease in accuracy.**

Keywords*—*Back-of-device interaction; copy and paste operations; mobile touch devices; touch interaction

I. Introduction

Various mobile touch devices have already been widely used in our everyday lives and enable users to manipulate user interfaces with a variety of touch interactions that previous feature phones cannot support [1]-[5]. Direct touch interaction has become the mainstream interactive technology on a mobile device mainly because it provides users with better performance and experience through natural, easy-to-use, and intuitive touch gestures.

Despite the numerous advantages, direct touch interaction still has many limitations that require further improvements, especially when it is applied to mobile devices. Due to the small screen size of mobile devices, touch interaction design for mobile user interfaces is usually tedious and time-consuming. Taking the copy operation as an example, the current technique utilizes a long-press action applied on the target to trigger the copy menu, and then utilizes a tap action applied on the pop-up copy menu to complete the copy of the target. Obviously, the long-press action is already very time-consuming; acquiring the copy menu takes even more time. Similar issues exist in the paste operation as well. In the meanwhile, however, as the computing power of mobile devices continues to increase, more and more complex applications, e.g. image editing software, slideshow editing software, and storytelling software, have already been available to mobile users. Apparently, simple operations such as copying and pasting are often used in these mobile applications. Therefore, how to further improve these simple and frequently used operations on mobile touch devices is an important research topic that HCI researchers should pay more attention to and explore.

The author's previous work in [6] explored the use of back-of-device touch input for promoting front-of-device touch interactions on mobile devices, for instance, to enhance mobile text entry or to augment the zooming operations in a map application. In this paper, the author extends the use of BackAssist [6] to enhance the copy and paste operations on mobile touch devices. The prototype BackC&P utilizes the back-of-device touch input provided by BackAssist to switch the current system mode to the copy mode or paste mode. In the copy mode, a front-of-device tap on the target will complete the copy of the target; in the paste mode, a front-of-device tap on the destination will complete the paste of the target.

The purpose of BackC&P is to take advantage of back-of-device touch input to improve the user performance of completing copy and paste operations on mobile touch devices. The results of the user study indicate that BackC&P was approximately twice faster than the currently used technique on mobile devices, and there was no significant increase in the error rate.

The reminder of this paper is as follows. The paper begins with a review of a series of important research literature on back-of-device interaction in Section II. After that, the interaction design of the technique BackC&P is introduced in Section III. Then, a user study comparing user performance between using BackC&P and the currently used technique is described in Section IV, followed by a detailed comparative analysis of efficiency and accuracy in Section V. Finally, some of the research results in terms of efficiency and accuracy are discussed in Section VI. Finally, the paper is concluded in Section VII.

II. Related Work

The research area that is most relevant to this research is back-of-device interaction. As its name suggests, back-of-device interaction makes use of various input units on the rear of a device to complete multifarious interactive tasks, such as text entry, target acquisition, mobile authentication, and so on. It can be used either as an exclusive manipulation technique or together with other interactive techniques, thus bringing many benefits that can improve user performance and experience in many aspects.

A. Exclusive Manipulation via Back-of-device Interaction

When it comes to back-of-device interaction, the first reaction is that it can address the occlusion problem and the fat finger problem. One of the best-known examples is NanoTouch [7] presented by Baudisch and Chu. It enables users with back-of-device touch input to interact with digital contents that are displayed on the tiny screen of a very small handheld device.

Back-of-device interaction can also be used for promoting one-handed mobile interaction. Yang et al. [8] augmented a PDA with cursor manipulation by attaching an optical sensor on the rear of the device. With the onscreen cursor, which was controlled by back-of-device input, a user could acquire the targets located in the places where the thumb could not reach. Hasan et al. [9] also explored one-handed back-of-device cursor interaction. Their findings indicated that compared with absolute mode cursor input, relative mode cursor input achieved better performances in both positioning the cursor and selecting the targets. Fan and Coutrix [10] explored the effect of asymmetry between preferred and non-preferred hands on user performance. Their study found that the preferred hand performed better in target acquisition tasks, but for steering tasks, they found little performance difference between preferred and non-preferred hands.

Mobile text entry is another research hotspot in back-of-device interaction. With a back-attached keyboard, RearType [11] allowed users to input text on a tablet by operating the physical keyboard on its rear. In order to keep mobile devices to their original form factor, Sandwich Keyboard [12] utilized a back-adhered multi-touch sensor to substitute the back-attached physical keyboards. In addition, Buschek et al. [13] added a machine-learning algorithm to Sandwich Keyboard to reduce the typing errors. Cui et al. proposed BackSwipe [14] which enabled a user to enter text or trigger a command by drawing a word-gesture on the back of a mobile device.

Researchers have also explored employing back-of-device interaction to support other mobile manipulation scenarios. For example, Luca et al. [15], Leiva et al. [16], and Kulshreshtha and Arif [17] explored realizing mobile device authentication through back-of-device interaction to address the problem of shoulder surfing. For another example, Granell and Leiva [18], [19] utilized the built-in gyroscope and accelerometer to implement tap-based back-of-device interaction, which could be used to control camera and game applications. Furthermore, Shimon et al. [20] investigated user-defined back-of-device gestures for a series of frequently used tasks on mobile devices. They found that for the vast majority of the tasks, participants had varying mental models when designing back-of-device gestures to complete them.

Although back-of-device interaction used as an exclusive input technique can make many achievements, e.g. addressing hand occlusion and “fat fingers”, supporting touch manipulation on tiny displays, and so on, it still has some limitations. On one hand, although back-of-device input addresses hand occlusion, the performance may not be as efficient as that of front-of-device touch input [21]. The results of a user study [22] show that compared with front-of-device touch input, back-of-device touch input achieves more accurate but much slower performance in conducting pointing tasks on a mobile device. On the other hand, when a user acquires onscreen targets by tapping, back-of-device touch interaction tends to be inferior to its front-of-device counterparts because the user’s operating fingers are occluded by the device itself [23], thereby failing to provide the user with visual clues of the operating fingers which are very important for accurately acquiring the targets. Therefore, combining back-of-device interaction with other interaction techniques rather than using it alone may better exert its strengths.

B. Hybrid Manipulation with Back-of-device Interaction

Many researchers have conducted studies on combining back-of-device interaction with other interactive techniques to augment mobile device manipulation.

Corsten et al. [24] presented BackXPress, which made use of back-of-device pressure input to switch between different quasi-modes for augmenting front-of-device touch interaction. Chen et al. [6] presented BackAssist, which utilized the combinations of on and off states of the two fingers resting on the rear of a mobile device to augment mobile text entry and zooming operations in a mobile map application. Huang et al. [25] proposed TapNet, which could identify taps on a smartphone while simultaneously recognizing various tap properties, such as direction and location. With TapNet, users could utilize back-of-device or edge tapping with other forms of interaction, such as tilt and touch, to complete tasks on their mobile devices.

One-handed mobile interaction was augmented by two-sided touch interaction as well. InfiniTouch [26] enabled touch input across the entire device surface of a smartphone while maintaining the standard smartphone form factor. Through a machine learning technique, InfiniTouch could identify all fingers during single-handed interaction. Le and colleagues also investigated fingers’ comfortable area [27] and safe area [28] for one-handed smartphone interaction, which could guide the design of interactions on the back and edges.

LucidTouch [29] took advantage of a technique, which was named pseudo-transparency, to overlay the video images of the user’s hands, which were behind the device and could not be seen by the user, onto the screen of the device. With the augmented visual feedback, users could manipulate the targets on a mobile device’s screen more accurately compared with the other back-of-device interaction techniques without such visual feedback.

C. Back-of-device Interaction for Copy and Paste Operations

Among the above-mentioned studies on back-of-device interaction, several involve the copy and paste operations. In [20], participants were asked to create gestures to complete the copy and paste tasks. However, the results of their study showed that there was little consensus on the gestures designed by the participants for these two tasks. When designing gestures, some participants mimicked keyboard shortcuts, and completed copy and paste operations by respectively drawing “C” and “V” on the back of the device. Cui et al. [14] proposed using word-gesture interaction to trigger commands. According to their design, a user could complete the copy operation by input “copy” or “replicate” on the device’s back. However, they did not implement their design on a real device. In study [26], several use cases were demonstrated. For instance, with InfiniTouch [26], a user could swipe down with the index finger to copy and swipe down with the middle finger to paste. However, their study did not verify the usability of the technique through experiments.

III. BACK-OF-DEVICE INTERACTION AUGMENTED COPY-AND-PASTE

The copy and paste operations are frequently used on various electronic devices. Compared with the techniques used on desktop computers, the current technique used on mobile devices is apparently more time-consuming, as illustrated in Fig. 1. For example, the long-press action is used for triggering the copy menu and even for triggering the paste menu until the tap action replaces it to complete the same task.

The author’s previous work in [6] explored making use of the two resting fingers, the index finger and the middle finger of the holding hand, on the rear of a mobile device to generate back-of-device touch input for augmenting the front-of-device touch interaction by the other hand. The hardware of the prototype, BackAssist, was built by attaching two off-the-shelf smartphones in a back-to-back fashion. Similar hardware prototypes were also utilized in many previous studies [12], [13]. The appearance of the prototype is shown in Fig. 2. The results of the user study indicate that the back-of-device input of BackAssist is easy-to-learn and can be efficiently and accurately used by ordinary mobile users [6]. Some applications enhanced by BackAssist have also been developed. For example, utilize the back-of-device input to switch between the lowercase page and the uppercase page of a soft keyboard [6].

In this paper, the author extends the use of BackAssist and explores utilizing the combinations of on and off states of the two fingers, respectively resting on Zone 1 and Zone 2 (see Fig. 2), for augmenting copy and paste operations on a mobile device. The interaction technique is named BackC&P.

With BackC&P, back-of-device input can be used for switching the current system mode to the copy mode or the paste mode, thus saving the time for the operations compared with those of currently used techniques. In the present implementation, the system modes are controlled by the back-of-device inputs, as shown in Table I. In order to complete a copy operation, the user first lifts up his/her finger on Zone 1 to switch the current system mode to the copy mode, and then taps the target by the other hand to copy the target, as shown in Fig. 3(b). Similarly, to complete a paste operation, the user first raises the finger on Zone 2 to switch the system mode to the paste mode, and then taps the desired position to paste the copied target there, as shown in Fig. 3(c). With BackC&P, there is no pop-up copy menu or paste menu, so the time for acquiring the copy menu or the paste menu is also saved. To sum up, theoretically, BackC&P can tremendously reduce the time for completing copy and paste operations compared with the existing techniques used on mobile touch devices.

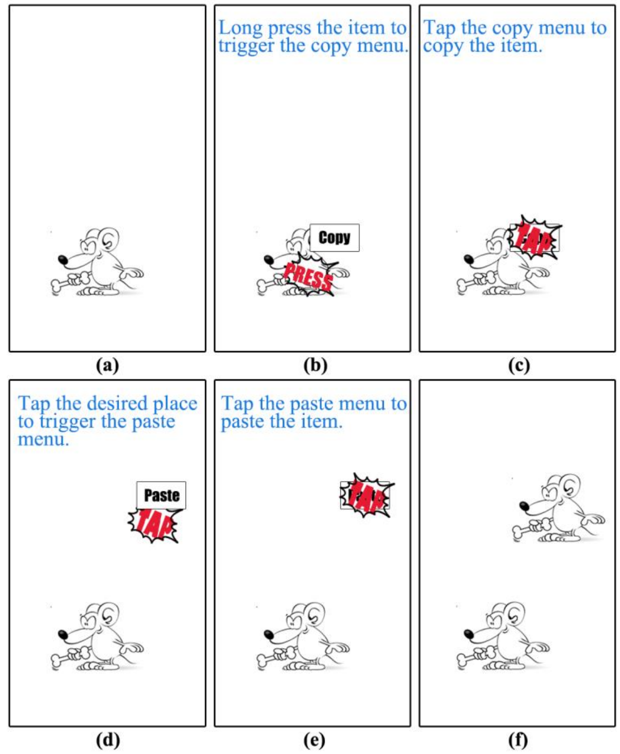

Fig. 1. A diagram demonstrates how to perform copy and paste operations with the currently used technique on a mobile touch device.

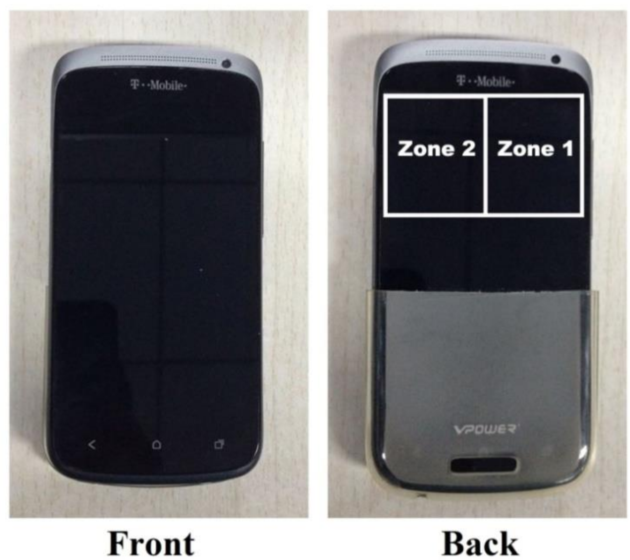

Fig. 2. The appearance of the hardware prototype.

TABLE I. THE MODES GENERATED BY BACK-OF-DEVICE INPUT

	Zone 1 without index finger on	**Zone 1 with index finger on**
Zone 2 without middle finger on	Usual Mode I	Paste Mode
Zone 2 with middle finger on	Copy Mode	Usual Mode II

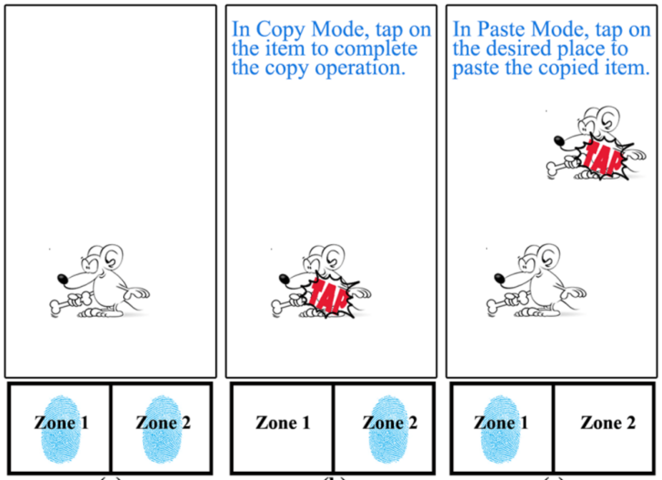

Fig. 3. A diagram of how to perform copy and paste operations with BackC&P. The blue fingerprints in the picture indicate that the corresponding finger(s) is/are on the specific Zone(s).

It should be noted that BackC&P can only save the time for the copy operation and the paste operation rather than the time for the navigation phase. The navigation time is the time that is taken to navigate from the copy position to the paste position. It may include the time for scrolling off-screen contents into the screen, the time for switching from one application to another, and so on. Usually, during a complete copy-and-paste operation, navigating to the desired place to paste the copied target may take the user a lot of time [30], [31]. Sometimes, the navigation time is much longer than the sum of the copy time and the paste time.

IV. User Study

Based on the previous analysis on the procedures of copy and paste operations on mobile devices, BackC&P is able to improve a user's performance at least in terms of the completion time. In order to verify the theoretical analysis, a user study was conducted to compare users' performances in using BackC&P and the currently used technique. Specifically, the author hoped to figure out whether BackC&P could improve users' performance in conducting copy-and-paste tasks. And if so, to what extent? In addition, the author wanted to get a more complete understanding of BackC&P. For instance, besides the completion time, were there other aspects of copy and paste operations on mobile devices affected by BackC&P? Finally, the author hoped to get the participants' first impressions on BackC&P.

A. Participants

Ten participants were recruited from a local university, ranging in age from 22 to 30. The participants' average age was 24.8 (SD = 2.10). All participants were right-handed people and they were all skilled in manipulating mobile touch devices.

B. Apparatus

The hardware prototype described in study [6] was used in this study. The experimental software was written in Java and Android SDK.

C. Task and Procedure

A copy-and-paste task was designed to simulate real copy-and-paste tasks on a mobile device for the user study. In order to minimize the impact of the navigation phase on the completion time, in the copy-and-paste task, the target to be copied and the destination to paste the copied target were presented in a single display. Therefore, the participants did not need to search for an off-screen destination by scrolling through the screen view or switching to another application.

The copy-and-paste task could be conducted by both BackC&P and the currently used technique which the author called it the traditional technique in this study. In real practice on current mobile devices, the paste menu could be triggered either by a long-press action or by a tap action, so both methods were enabled to activate the paste menu although the participants were encouraged to trigger the paste menu by tapping upon the destination, which could reduce the time for the paste operation.

Each trial began with displaying a start button below the inactivated target. The distance between the center of the target and the center of the start button was 370 pixels. After the participant successfully acquired the start button, timing started and the target, a blue circle in the center of the display, was activated at the same time. The participant then conducted the copy operation. Once the target was successfully copied, four circles with the radius of 10 pixels larger than that of the target would be rendered in the four locations around the target, respectively in its northwest, northeast, southeast and southwest. The four circles represented the potential locations for pasting the copied target. The real location for pasting the target was called the destination. The destination was highlighted in green while the other three circles, serving as distractors, were rendered in grey. Finally, the participant pasted the target in the destination.

Before the study began, each participant was required to fill out a pre-study questionnaire to gather demographics. Then a brief introduction about the copy-and-paste task and a training session about how to perform the copy-and-paste task were given. After that, the participant was allowed to practice performing the tasks. When he or she felt skilled enough, ten blocks of trials would be given to complete. Short breaks were permitted between trials or blocks. At the conclusion of the study, each participant was asked to fill out a post-study questionnaire to collect subjective feedbacks.

D. Experimental Design

In the copy-and-paste task, three target sizes (radius = 30, 50, 70 pixels; respectively similar to the sizes of keys of the virtual keyboard, app icons, and thumbnails of pictures on a smartphone), two target-destination (from the center of the target to the center of the destination) distances (224 and 335 pixels, as shown in Fig. 4), and four potential locations for the destination were used. As a result, there were totally 24 (Size $\times$ Distance $\times$ Destination) different tasks for each interaction technique.

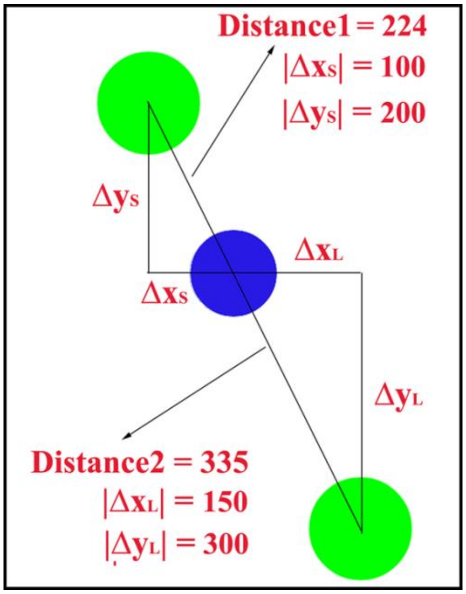

Fig. 4. The two target-destination distances for the task (the subscript 'S' denotes short and the subscript 'L' denotes long).

A within-subjects design was utilized for the experiment. Each participant conducted the copy-and-paste tasks using both BackC&P and the traditional technique. The order of using the two techniques was counterbalanced. For each technique, there were totally 10 blocks of trials. Each block contained all the 24 different copy-and-paste tasks and these tasks would appear in a random order.

To sum up, the experiment design was as follows:

10 participants ×

2 Techniques ×

10 blocks ×

3 Sizes ×

2 Distances ×

4 Destinations

= 4800 trials.

V. Results and Analysis

A. Completion Time Analysis

The completion time is the time that is taken between the acquisition of the start button and the completion of pasting the copied target. It includes the copy time and the paste time. The copy time is defined as the time between the selection of the start button and the completion of copying the target. The paste time is defined as the time between the completion of the copy operation and the completion of pasting the copied target.

Before conducting the data analysis, the records that were marked as error ones were removed from the dataset. The grand mean of the completion time of the adjusted data was 2.10 seconds (SD = 1.06 seconds).

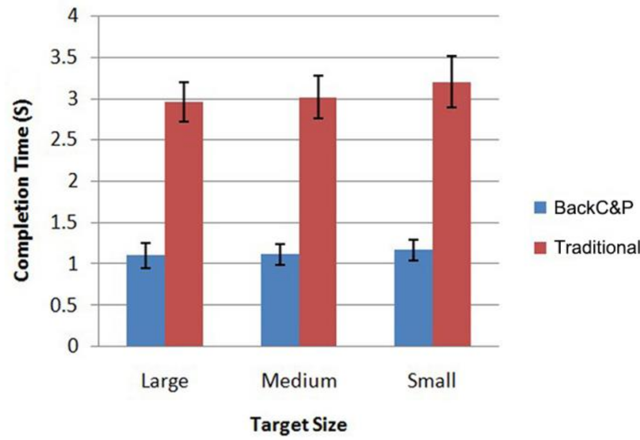

Fig. 5. Mean completion times of both techniques for each target size.

After the data adjustment, a repeated measures ANOVA was applied to the collected records. The result demonstrated a significant difference for Technique ($F(1,9) = 666.272$, $p < 0.001$), with the mean completion times of 1.13s for BackC&P and 3.06s for the traditional technique. BackC&P was almost twice faster than the traditional technique. One thing should be pointed out was that in the pre-study questionnaires nine participants chose the older method, which utilized the long-press action, when they answered the question "How do you trigger the paste menu on your smartphone?" However, after they were encouraged to use the tap action to trigger the paste menu in the study, only eight of the 2400 trials were completed by using the long-press actions. Therefore, if the participants utilized their frequently used method in the study, the difference in the completion times would have been even greater.

A significant main effect for Size ($F(2,18) = 17.813$, $p < 0.001$) was also found. Post hoc analysis indicated that the completion time of small targets (30 pixels) was significantly different from those of medium (50 pixels) and large targets (70 pixels). This was in line with the author's expectation that it would take more time to copy and paste a target whose size was much smaller than the fingertip of the operating finger. In addition, there was a significant interaction between Technique and Size ($F(2,18) = 12.526$, $p < 0.001$). A post hoc test indicated that BackC&P performed significantly better than the traditional technique in all three target sizes. Fig. 5 illustrates the mean completion times of both techniques for each target size.

The author also calculated the mean completion time of the trials that were operated by BackC&P and marked as error ones. The result was 2.60s, which was still shorter than that (3.06s) of the correct trials which were conducted by the traditional technique.

B. Copy Time Analysis

The grand mean copy time of the adjusted dataset was 1.16s (SD = 0.77s). A repeated measures ANOVA revealed a significant main effect for Technique ($F(1,9) = 616.068$, $p < 0.001$), with mean copy times of 0.48s and 1.81s for BackC&P and the traditional technique respectively. A significant main effect for Size ($F(2,18) = 9.506$, $p < 0.01$) was found as well.

Post hoc analysis indicated that the copy time of small targets was significantly different from those of medium and large targets. There was a significant interaction between Technique and Size ($F(2,18) = 6.151$, $p < 0.01$). Post hoc analysis showed that BackC&P performed significantly better than the traditional technique in all three target sizes. Fig. 6 shows the mean copy times of both techniques for each target size.

C. Paste Time Analysis

The grand mean paste time of the adjusted data was 0.95s (SD = 0.33s). A repeated measures ANOVA revealed a significant difference for Technique ($F(1,9) = 321.630$, $p < 0.001$), with mean paste times of 0.65s and 1.24s for BackC&P and the traditional technique respectively. A strong main effect for Size ($F(2,18) = 45.612$, $p < 0.001$) was also observed. Post hoc analysis indicated that the paste time of each target size was significantly different from those of the others. In addition, there was a significant interaction between Technique and Size ($F(2,18) = 20.731$, $p < 0.001$). Post hoc analysis showed that BackC&P performed significantly better than the traditional technique in all three target sizes. Fig. 7 shows the mean paste times of both techniques for each target size.

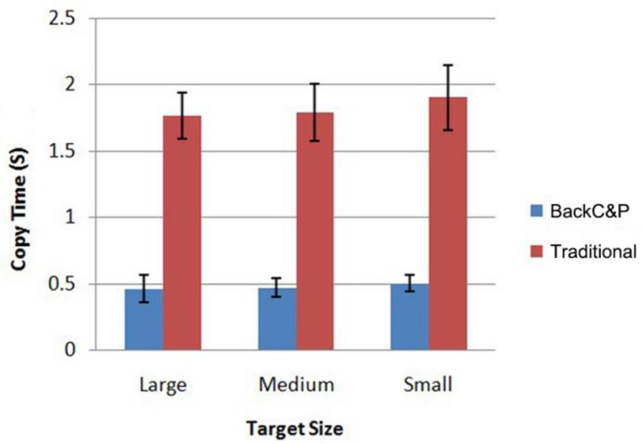

Fig. 6. Mean copy times of both techniques for each target size.

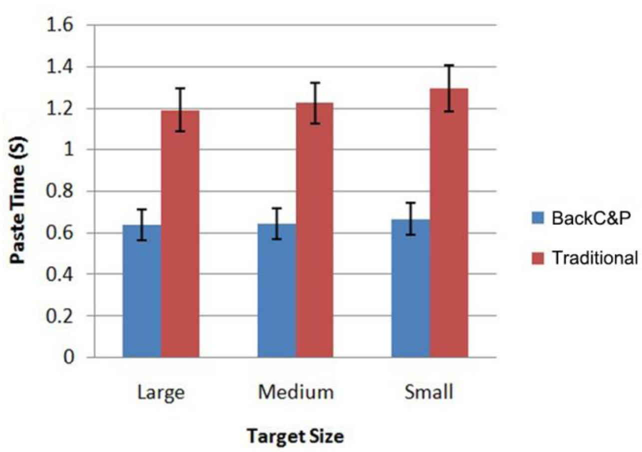

Fig. 7. Mean paste times of both techniques for each target size.

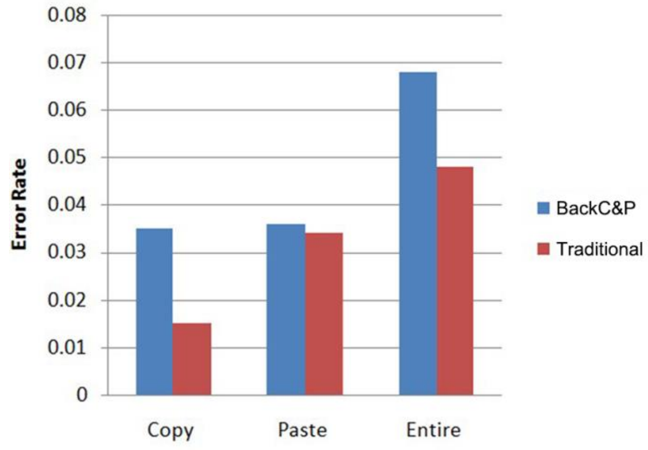

Fig. 8. Error rates of the copy operation, the paste operation, and the whole copy-and-paste operation.

D. Entire Error Analysis

There were totally 276 trials marked as error ones, in which participants made either copy errors or paste errors, or both. The grand mean error rate was 5.8%.

A repeated measures ANOVA showed no significant difference for Technique ($F(1,9) = 3.447$, $p = 0.096$), with mean entire error rates of 6.8% and 4.8% for BackC&P and the traditional technique respectively. Also, no significant main effect for Size ($F(2,18) = 2.059$, $p = 0.157$) was found. Fig. 8 shows the error rates of the copy operation, the paste operation, and the whole copy-and-paste operation.

E. Copy Error Analysis

There are four types of errors, which may occur during a copy operation, when using BackC&P, as shown in Table II. For the traditional technique, there are two types of errors: pressing outside the target and missing the copy menu.

There were totally 122 trials marked with copy errors, of which 85 trials was performed by BackC&P and 37 trials by the traditional technique. The number of copy errors of each error type of BackC&P was listed in Table II. Note that, there were two trials which committed both Copy Error I and Copy Error II. For the traditional technique, seven errors belonged to pressing outside the target while 30 errors pertained to tapping outside the copy menu.

The grand mean of the copy error rate was 2.5%. A repeated measures ANOVA revealed a significant difference for Technique ($F(1,9) = 9.618$, $p < 0.05$), with mean copy error rates of 3.5% and 1.5% for BackC&P and the traditional technique respectively. No significant main effect for Size ($F(2,18) = 1.696$, $p = 0.211$) was found.

F. Paste Error Analysis

There are four types of errors, which may occur during a paste operation using BackC&P, as shown in Table III. For the traditional technique, there are three types of errors: pressing outside the destination (Traditional Paste Error Type I, abbreviated TPET I), tapping outside the destination (TPET II), and missing the paste menu (TPET III).

TABLE II. THE COPY ERROR TYPES OF BACKC&P

Error Type	Descriptions	Error Number
Copy Error I	Hit the target on the front screen while the back-of-device input is in the Usual Mode II.	68
Copy Error II	Hit the target on the front screen while the back-of-device input is in the Paste Mode.	7
Copy Error III	Hit the target on the front screen while the back-of-device input is in the Usual Mode I.	0
Copy Error IV	Miss the target on the front screen.	12

TABLE III. THE PASTE ERROR TYPES OF BACKC&P

Error Type	Descriptions	Error Number
Paste Error I	Hit the destination on the front screen while the back-of-device input is in the Usual Mode II.	76
Paste Error II	Hit the destination on the front screen while the back-of-device input is in the Copy Mode.	5
Paste Error III	Hit the destination on the front screen while the back-of-device input is in the Usual Mode I.	1
Paste Error IV	Miss the destination on the front screen.	6

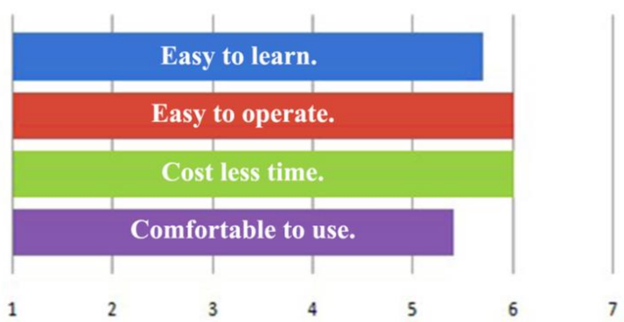

Fig. 9. The summary of answers collected from the post-questionnaires.

There were totally 168 trials marked with copy errors, of which 86 trials was conducted by BackC&P and 82 trials by the traditional technique. The number of paste errors of each error type of BackC&P was listed in Table III. Note that, there were two trials which committed both Paste Error I and Paste Error II. For the traditional technique, two errors belonged to TPET I, 24 errors belonged to TPET II, and the other 65 errors belonged to TPET III.

The grand mean paste error rate was 3.5%, which was higher than the grand mean copy error rate. A repeated measures ANOVA demonstrated no significant difference for Technique ($F(1,9) = 0.047$, $p = 0.834$), with mean paste error rates of 3.6% and 3.4% for BackC&P and the traditional technique respectively. In addition, no significant main effect for Size ($F(2,18) = 0.714$, $p = 0.503$) was found.

G. User Feedback

At the end of the study, a post-study questionnaire was answered by each participant. The purpose of the questionnaire was to collect the participants' first impressions on the interaction technique BackC&P.

From the post-study questionnaires, positive feedback on BackC&P was received from the participants that six of the ten participants chose BackC&P as their preferred technique for completing the copy-and-paste tasks. The other four participants treated the two techniques equally. None of participants specifically chose the traditional technique as their preferred technique.

In the post-study questionnaire, each participant was also asked to rate the items on a scale from 1 to 7, with 7 being the strongly agree. The summary of the collected results from the questionnaires is illustrated in Fig. 9. It can be seen that, on the whole, the participants deemed that BackC&P was easy to learn, easy to operate, comfortable to use, and less time-consuming.

VI. DISCUSSIONS

From the user study, the author found that BackC&P outperformed the traditional copy-and-paste technique on mobile devices in terms of efficiency. BackC&P achieves this mainly for two reasons. To begin with, BackC&P requires less front-of-device touch interactions for item acquisition than the traditional technique does. It accomplishes a copy-and-paste task with only two front-of-device touch actions, a tap to acquire the target and another tap to acquire the destination. As for the traditional technique, it needs four item acquisitions on the frontal touchscreen to complete the same task. In addition, BackC&P does not utilize the action of long-press, which is particularly time-consuming compared to interactions such as tapping [32], thereby tremendously saving the time for the copy operation.

In terms of error rate, the author found that for BackC&P, the most majority of the errors in copy and paste operations were caused by unsuccessfully lifting up the dedicated finger on the rear rather than by lifting the wrong finger on the rear, or by unsuccessfully acquiring the target or destination on the front screen. The author speculates that this might be due to the participants' attempt to finish the tasks in a shorter time. As copy and paste operations used in daily life are not as many and intensive as in the user study, these types of errors may be far less in actual use.

Also in terms of errors, the author found that for the traditional technique, the participants committed many more errors in acquiring the paste menu than acquiring the copy menu. The author deems that this difference is mainly due to the different mechanisms by which they trigger the two types of menus. For the copy operation, the user long-presses the target to trigger the copy menu, so he or she has more time to prepare to acquire the copy menu compared with the time to prepare to acquire the paste menu which is triggered by tapping. That is, acquiring a menu by a tap action following another tap action is less accurate than acquiring a menu by a tap action following a long-press action. It is interesting and meaningful to conduct a more comprehensive study in the future to investigate on the user performance in completing various tasks that require successive touch actions. The results will provide us with more insights into designing better mobile touch user interfaces.

VII. Conclusion

Direct touch input enables users to interact with mobile devices with spontaneous and easy-to-use touch gestures. However, its limitations, e.g. time-consuming, still exist and negatively affect user experiences, especially in some frequently used simple tasks, e.g. copy and paste operations. In this paper, BackC&P, a mobile interactive technique which augments the copy and paste operations through the assistance of back-of-device touch input, is presented. The results of the user study indicate that with BackC&P users' efficiency in conducting copy and paste operations was tremendously improved on a mobile touch device, nearly two times faster than the currently used technique, and the accuracy was not significantly degraded during the entire process.

The current technique supports to copy and paste individual items, such as an image, a word, a chat message, a web link, etc. In the future, the author will explore extending the current technique to copy and paste a series of continuous items, such as several continuous words or sentences.

Acknowledgment

The author would like to express gratitude to the participants who participated in the user study. This research is funded by the Scientific Research Foundation of CUIT (No.KYTZ202274) and the National Natural Science Foundation of China (No. 62172081).

References

[1] M.Jain and R. Balakrishnan, "User learning and performance with bezel menus," in Proceedings of the 2012 CHI conference on Human Factors in Computing Systems (CHI), 2012, pp.2221-2230.

[2] B. Poppinga, A. S. Shirazi, N. Hence, W. Heuten, and S. Boll, "Understanding shortcut gestures on mobile touch devices in Proceedings of the 16th international conference on Human computer interaction with mobile devices and services (MobileHCI), 2014, pp.173-182.

[3] K. Schramm, C. Gutwin, and A. Cockburnl, "Supporting Transitions to Expertise in Hidden Toolbars," in Proceedings of the 2016 CHI conference on Human Factors in Computing Systems (CHI), 2016, pp.4687-4698.

[4] T. Han, J. Liu, K. Hasan, M. Fan, J. Kim, J. Li, X. Fan, F. Tian, E. Lank, and P. Irani, "PinchList: Leveraging Pinch Gestures for Hierarchical List Navigation on Smartphones," in Proceedings of the 2019 CHI conference on Human Factors in Computing Systems (CHI), 2019, Paper No.: 501, pp.1 - 13.

[5] Z. Xu, Y. Meng, X. Bi, and X. Yang, "Phrase-Gesture Typing on Smartphones," in Proceedings of the annual ACM symposium on user interface software and technology (UIST), 2022, Article 55, pp.1–11.

[6] L. Chen, D. Chen, and X. Chen, "BackAssist: Augmenting Mobile Touch Manipulation with Back-of-Device Assistance," IEICE Trans. Inf. & Syst., vol. E101-D, no. 6, pp. 1682-1685, June 2018.

[7] P. Baudisch and G. Chu, "Back-of-device interaction allows creating very small touch devices," in Proceedings of the 27th international conference on Human Factors in Computing Systems (CHI), 2009, pp. 1923- 1932.

[8] X. D. Yang, P. Irani, P.Boulanger, and W. Bischof, "One-handed behind-the-display cursor input on mobile devices," CHI EA, 2009, pp. 4501-4506.

[9] K. Hasan, X. D. Yang, H. N. Liang, and P. Inrani, "How to position the cursor?: an exploration of absolute and relative cursor positioning for back-of-device input," in Proceedings of the 14th international conference on Human computer interaction with mobile devices and services (MobileHCI), 2012, pp. 103-112.

[10] Z. Fan and C. Coutrix, "Impact of Hand Used on One-Handed Back-of-Device Performance," Proceedings of the ACM on Human-Computer Interaction, Vol. 4, Issue ISS, Article No.: 188, pp. 1–19, November 2020.

[11] J. Scott, S. Izadi, L. Rezai, D. Ruszkowski, X. Bi, and R. Balakrishnan, "Reartype: text entry using keys on the back of a device," In Proceedings of the 12th international conference on Human computer interaction with mobile devices and services (MobileHCI), 2010, pp. 171–180.

[12] O. Schoenlenben and A. Oulasvirta, "SandwichKeyboard: fast tenfinger typing on a mobile device with adaptive touch sensing on the back side," In Proceedings of the 15th international conference on Human computer interaction with mobile devices and services (MobileHCI), 2013, pp.175-178.

[13] D. Buschek, O. Schoenleben, and A. Oulasvirta, "Improving accuracy in back-of-device multitouch typing: a clustering-based approach to keyboard updating," In Proceedings of the 19th international conference on Intelligent User Interfaces (IUI), 2014, pp.57-66.

[14] W. Cui, S. Zhu, Z. Li, Z.Xu, X.Yang, I. Ramakrishnan, X. Bi, "Back-Swipe: Back-of-device Word-Gesture Interaction on Smartphones," in Proceedings of the 2021 CHI conference on Human Factors in Computing Systems (CHI), 2021, Article No.: 196.

[15] A. D. Luca, E. von Zezschwitz, N. D. H. Nguyen, M.-E. Maurer, E. Rubegni, M. P. Scipioni, and M. Langheinrich, "Back-of-device authentication on smartphones," in Proceedings of the 31st international conference on Human Factors in Computing Systems (CHI), 2013, pp. 2389-2398.

[16] L. A. Leiva and Alejandro Catala, "BoD taps: an improved back-ofdevice authentication technique on smartphones," in Proceedings of the 16th international conference on Human computer interaction with mobile devices and services (MobileHCI), 2014, pp. 63-66.

[17] S. Kulshreshtha and A. S. Arif, "Woodpecker: Secret Back-of-Device Tap Rhythms to Authenticate Mobile Users," in Proceedings of the 2020 IEEE International Conference on Systems, Man, and Cybernetics (SMC), 2020, pp. 2727-2733.

[18] E. Granell and L. A. Leiva, "Less Is More: Efficient Back-of-Device Tap Input Detection Using Built-in Smartphone Sensors," in Proceedings of the 2016 ACM International Conference on Interactive Surfaces and Spaces (ISS), 2016, pp. 5-11.

[19] E. Granell and L. A. Leiva, "βTap: back-of-device tap input with built-in sensors," in Proceedings of the 19th international conference on Human computer interaction with mobile devices and services (MobileHCI), 2017, Article No. 52.

[20] S. Shimon, S. Smith, N. John, G. Fahimi, and J. Ruiz, "Exploring User-Defined Back-Of-Device Gestures for Mobile Devices", in Proceedings of the 17th international conference on Human computer interaction with mobile devices and services (MobileHCI), 2015, pp. 227-232.

[21] J. O. Wobbrock, B. A. Myers, and H. H. Aung, "The performance of hand postures in front- and back-of-device interaction for mobile computing," Int. J. Hum.-Comput. Stud., vol. 66, no. 12, pp. 857-875, December 2008.

[22] L. Chen, D. Chen, and X. Chen, "A Comparison Study on Front- and Back-of-Device Touch Input for Handheld Displays," IEICE Trans. Electron., vol. E101-C, no. 11, pp. 880-883, November 2018.

[23] D. Wigdor, D. Leigh, C. Forlines, S. Shipman, J. Barnwell, R. Balakrishnan, and C. Shen, "Under the table interaction," in Proceedings of the annual ACM symposium on user interface software and technology (UIST), 2006, pp.259-268.

[24] C. Corsten, B. Daehlmann, S.Voelker, and J. Borchers, "BackXPress: Using Back-of-Device Finger Pressure to Augment Touchscreen Input on Smartphones," in Proceedings of the 2017 CHI conference on Human Factors in Computing Systems (CHI), 2017, pp.4654-4666.

[25] M. Huang, Y. Li, N. Nazneen, A. Chao, and S. Zhai, "TapNet: The Design, Training, Implementation, and Applications of a Multi-Task Learning CNN for Off-Screen Mobile Input," in Proceedings of the 2021

CHI conference on Human Factors in Computing Systems (CHI), 2021, Article No.: 282.

[26] H. Le, S. Mayer, and N. Henze, “InfiniTouch: Finger-Aware Interaction on Fully Touch Sensitive Smartphones, ” in Proceedings of the annual ACM symposium on user interface software and technology (UIST), 2018, pp. 779-792.

[27] H. Le, S. Mayer, P. Bader,and N. Henze, “Fingers’ Range and Comfortable Area for One-Handed Smartphone Interaction Beyond the Touchscreen,” in Proceedings of the 2017 CHI conference on Human Factors in Computing Systems (CHI), 2018, Paper No.: 31.

[28] H. Le, S. Mayer, B. Steuerlein, and N. Henze, “Investigating Unintended Inputs for One-Handed Touch Interaction Beyond the Touchscreen,” In Proceedings of the 21th international conference on Human computer interaction with mobile devices and services (MobileHCI), 2019, Article No.: 34.

[29] D. Wigdor, C. Forlines, P. Baudisch, J. Barnwell, and C. Shen, “Lucid-Touch: A See-Through Mobile Device,” in Proceedings of the annual ACM symposium on user interface software and technology (UIST), 2007, pp. 269–278.

[30] O. Chapuis and N. Roussel, “Copy-and-paste between overlapping windows,” in Proceedings of the 25th international conference on Human Factors in Computing Systems (CHI), 2007, pp.201-210.

[31] S. D. Zhao, F. Chevalier, W. T. Ooi, C. Y. Lee, and A. Aharwal, “AutoComPaste: Auto-completing text as an alternative to copy-paste,” in Proceedings of the International Working Conference on Advanced Visual Interfaces (AVI), 2012, pp.365-372.

[32] E. Oh, J. Hong, M. Cho, J. Choi, “Study on Behavioral Characteristics of 3D Touch in Smartphone,” Journal of the Ergonomics Society of Korea, vol.35, no.6, pp.551-568, December 2016.