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New chording text entry methods combining physical and virtual buttons on a mobile phone

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ABSTRACT

Traditional mobile phones depend on MultiTap, virtual or physical QWERTY keyboard for text entry, and they had some respective drawbacks include low input performance, occupying too large an area, high error rates, lack of feedbacks, etc. Therefore, some researches utilized the characteristics of the chording keyboard to improve input performance. Yet, as the learning efficiency of the chording keyboard is too low, users are not highly willing to learn. In view of that, this study combines the physical and virtual keys, and develops two chording input methods, MagArea and MemoryTap. After three days of learning, the fourteen experiment participants show effectively reduce error rates on MagArea, and they enhance their input speed on MemoryTap. In addition, excellent learning efficiency is found in the two methods, will be more motivated and willing to employ.

1. Introduction

Traditional cellphones mainly depend on MultiTap for text entry, the advantage of which is that it needs far fewer keys than a conventional keyboard. Yet, its input requires multiple or repeated presses, so the key strokes per character (KSPC) are increased (MacKenzie, 2002). Not only is input efficiency reduced, but it is also more likely to cause repetitive strain injuries (RSI) to a hand (Balakrishnan and Yeow, 2008). Consequently, the QWERTY layout is the mainstream mode of text entry widely adopted by newly-emerging smartphones. Whether installed physically or virtually on a cellphone, the standard QWERTY keyboard, which is normally 28 cm in width, is miniaturized on a 6-cm panel. Needless to say, the key size is not in line with most human fingers (Wigdor, 2004). To address this problem, many researchers have developed a large number of chording input devices, but the fact that their learning efficiency are too low has led to severe criticism (Kristensson, 2007; Tinwala and MacKenzie, 2009). With respect to the above, this study endeavored to develop new modes of chording text entry, which combine physical with virtual keys simultaneously pressed, as well as comply with principles of ergonomic operation and cognitive factors. In this way, the proposed text entry methods reduce the problems with input efficiency and operational errors caused by overly crowded and small keys on common cellphones and chording devices.

1.1. Chording text entry on mobile phones

To enter a character or command with a chording keyboard, users must press multiple keys simultaneously. For instance, the Half-QWERTY keyboard (Matias et al., 1993) relies on the space key as its control unit. Though it has only the left side keyboard, the left key is combined with the space key to produce a corresponding character on the right side through mirroring. Thus, the chording keyboard possesses the following features: fewer keys, a smaller size, high portability, operable in a mobile or unstable environments, and prevention of injury caused by repetitive force-applying (Billinghurst et al., 2009). Accordingly, it is suitable for mobile devices.

Twiddler was invented as a one-handed chording device (Lyons et al., 2006). With its keys arranged in alphabetic order, Twiddler enters a letter through the chording text entry of multiple keys. In addition, it can define a wide range of input characters, so there are many combinations that can be defined for the input of multiple characters, such as -ing and -tion (Wigdor, 2004). Although Twiddler can enhance the input efficiency of characters, some studies have shown that its floor entry rate is too low, its learning time too long, and its error rate too high (Kristensson, 2007; Tinwala and MacKenzie, 2009). Furthermore, with too many keys present, its key layout will have various influences on users of different gender, palm size, and finger length (Lyons et al., 2004). As a result, it is somewhat difficult to convert the hand-held Twiddler into a device fully compatible with mobile phones.

Wigdor and Balakrishnan developed two new modes of chording text entry for cellphones, i.e., TiltText and ChordTap (Wigdor

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and Balakrishnan, 2003). TiltText combines the MultiTap layout and four directional movements, namely, forward, backward, left, and right movements, to select a particular character. A similar concept is also found in ChordTap (Wigdor, 2004). ChordTap adds three chording keys to the back of the traditional 12-key flip phone, and the three keys are used to control the selection of characters on the front keyboard. This means that users must press the numeric key with one hand, and press one of the chord keys with the other. The above two methods divide the letters into individual groups; then, in the process of typing, a certain group is first selected through one key, and then a member of the group is selected through the corresponding key or the tilt angle. Thus, the problem connected with the high KSPC is effectively relieved. However, it is rather difficult for users to execute such a two-stage selection simultaneously, so input efficiency is still not improved.

1.2. *Ergonomic rules and design elements*

Text entry is a fairly complex process, involving visual, tactile, motion, memory, learning, and other cognitive functions. Moreover, they belong to different levels of cognitive processing. The process of text entry is subject to the biomechanical constraints of the hand. Whether perceptual and cognitive concepts are suitable will dominantly affect the user's final performance, such as the response time and accuracy rate of typing (Logan, 2003). Therefore, if a new input method is to be designed, ergonomic operation and cognitive compatibility must be emphasized.

According to Fitts' law concerning motion execution (Fitts, 1954), the keyboard layout should be arranged so that a finger travels the minimum distance necessary, allowing text entry efficiency to be improved. Moreover, some studies have shown that if two hands are used simultaneously to do a non-computing job, operational efficiency will be enhanced because of two-handed coordination (Sandnes and Aubert, 2007). Further, users' familiarity with the QWERTY keyboard, procedural memory, which here concerns fingers corresponding to different letters, should be incorporated into ergonomic considerations when typing actions are designed. Consequently, users need not invest too much cognitive effort while typing (McLoone et al., 2003). Realizing that the procedural memory has a subtle effect on users, many researchers have employed the transfer effect of learning to conduct relevant designs or studies (Hwang and Lee, 2005; MacKenzie and Soukoreff, 2002; Matias et al., 1993; McLoone et al., 2003; Sandnes and Aubert, 2007). Contrarily, if the layout design is different from the user's original procedural memory, it will cause interference (McLoone et al., 2003). In addition to enhancing motional performance, researchers have also changed the user interface, singled out the character keys on the touchscreen dynamically, enlarged the area of the selected characters, and shortened the distance between characters in order to enhance input performance and reduce error rates (Merlin and Raynal, 2010).

Apart from an ergonomic layout matching users' actions, cognitive concepts must be consistent with users' intuition, past experience and memory. Roughly categorized, the methods for text entry are based on two kinds of arrangement: alphabetic order and QWERTY layout. However, which of the two layouts is most suitable for users? Sandnes and Aubert (2007) argued that the QWERTY layout is much easier for users to become familiar with, and therefore is more suitable for the arrangement of letters. Hence, they took the advantage of users' spatial familiarity with the QWERTY layout, and designed a joystick that enabled users to perform text entry. Hwang and Lee (2005) also presented their assertion that the alphabetic order makes it more difficult for user to memorize and results in low typing efficiency. Accordingly, they developed the 3×4 mobile keyboard, the layout of which is similar to QWERTY, resulting in better performance than the standard keyboard with an alphabetic layout.

The cognitive compatibility of encoding is also a very important factor. For instance, Matias et al. (1993) developed the Half-QWERTY chording keyboard, which is operated only with the left hand. The corresponding characters originally typed with the right hand are in the form of mirrored entities. Nevertheless, they did not account for why the keyboard design was based on the mirror approach instead of spatial congruence. Munhall and Ostry (1983) reported that the motional control of the left and right hands is through mirroring rather than direct spatial congruence (cite from Billinghurst et al., 2009). Further, according to the findings regarding the stimulus-response compatibility effect (SRC effect), different hand postures will affect encoding patterns, which will vary with the relationship between visual stimulus and finger reaction (Ehrenstein et al., 1989).

2. Observation: users' typing postures on different phones

Understanding the typing postures of how users operate their mobile phones is crucial for developing new ways of interaction for text entry chording methods. Based on the observation by Gold et al. (2012), three postures were found to occur most often by mobile phone users: holding the phone in one hand while using the index finger of another hand, holding the phone in the palm of the hand while using the thumb of the same hand, and using both hands to hold the phone and typing with both thumbs (Fig. 1). Furthermore, this study tried to analyze the relationship between the typing postures and phones with different typing methods. Therefore, in this stage, the main purpose was to observe the postures when using phones with different typing methods.

Forty-six participants (24 men and 22 women), aged between 18 and 39 ($M = 25.48$, $SD = 4.88$) were recruited from National Cheng Kung University (NCKU). They were asked to perform text entry on their own mobile phone. The results show that mobile phones could be roughly characterized into two types: physical and virtual (touchscreen) keyboards, and the layout of those two keyboards can also be divided into MultiTap and QWERTY. The participants also demonstrated three operating postures that resembled to the result of Gold et al. As Table 1 shown, mobile phones with a physical keyboard and MultiTap style were owned by most participants, and they tended to hold the phone with their right hand and type with their right thumb. Phones with virtual keyboards most frequently featured the QWERTY layout, where participants tended to use the left hand to hold the phone and operate it with their right index finger.

However, to determine which of the above three operating postures is suitable for the new chording methods can be compared via the two perspectives. First, the operating posture needs to avoid the occlusion problem (fat finger problem) (Wigdor et al., 2007) where the user's finger is too big and induces the error of touching neighboring keys. Consequently, some researchers have compared different finger precision of target selection and found that the performance of the index finger was relatively better than the thumb (Sheik-Nainar, 2010; Wang and Ren, 2009). Secondly, the movement time of different operating postures can also be considered as the reason for new design. Silfverberg et al. (2000) compared right hand holding, right thumb typing and left hand holding, right index typing on a MultiTap mobile phone, and used Fitts' law to predict the movement times of two operating postures. They found the input by left hand holding, right index typing achieved a shorter movement time and lowered the index of difficulty. Furthermore, if users held the device with their left hand and typed with their right index finger, the new design could be operated by both hands. This method was found to also reduce the