A Japanese Bimanual Flick Keyboard for Tablets That Improves Display Space Efficiency

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Abstract: Tablets, as well as smartphones and personal computers, are popular as Internet clients. Tablet users often use QWERTY software keyboards to enter text. Such a software keyboard usually uses large display space, and requires its user to largely move their fingers. This paper proposes a Japanese bimanual flick keyboard for tablets that improves display space efficiency by using 10 character keys. The paper presents an implementation of the keyboard for an Android tablet, and describes an experiment on its performance compared with a QWERTY software keyboard. Since the results of a preliminary experiment indicated a problem with the key layout, the main experiment further introduced an L-shaped layout and a Γ-shaped layout for comparison. The main experiment examined the keyboard's input speed, accuracy, and subjective evaluation, and the results showed trade-offs among these layouts.

1 INTRODUCTION

Tablet users often use QWERTY software keyboards that occupy large display space. A split keyboard is a software keyboard that improves display space efficiency. By splitting a QWERTY keyboard, it allows its user to put both hands at natural positions. The improvement of display space efficiency is good for multitasking.

In Japan, there are about as many users of "flick" keyboards as QWERTY keyboard users. Flick is a gesture operation especially used for character input on touch-screen devices. Flick input usually makes its user to touch a key with a finger and then slide the finger upward, downward, to the left, or to the right for input. Since many flick keyboard users do not use the roman letter input, it is difficult for them to use a QWERTY keyboard. Especially, Japanese young people often find difficulty in efficiently operating QWERTY keyboards.

This paper proposes a Japanese input software keyboard that integrates flick input with a split keyboard. It largely improves display space efficiency and also shortens finger movement. Its layout consists of 2×5×2 keys, and its key size is 60×60 pixels. This layout reduces the necessary display space by 70% in the portrait mode and by 81% in the landscape mode, compared with a QWERTY keyboard with the maximum display width. A preliminary experiment was conducted to explore input method problems, appropriate key sizes, and appropriate key layouts and also to estimate user fatigue. The results of the preliminary experiment indicated a problem with its 5-row key layout. Therefore, L-shaped and Γ-shaped keyboard layouts were further added. The L-shaped and Γ-shaped layouts reduce the necessary display space by 73% in the portrait mode and by 83% in the landscape mode. In addition, the final implementation included the function of converting Japanese kana characters to Chinese characters and placed it on the right side of the keyboard.

To show complementary values of the proposed keyboard, a main experiment on the comparison of the 5-row, L-shaped, and Γ-shaped layouts with the QWERTY key layout was conducted. The main experiments used two kinds of input tasks, sentence input and word repetition input. The results indicate that the error rates of the proposed layouts had valuable complements in the experiments of both kinds of input.

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2 RELATED WORK

Various research has been done on keyboards for tablets. Sax et al. proposed an ergonomic QWERTY tablet keyboard (Sax, Lau, & Lawrence, 2011). Bi et al. proposed a bimanual gesture keyboard to reduce display space and to shorten finger movement (Bi, Chelba, Ouyang, Partridge, & Zhai, 2012). Hasegawa et al. studied input of a software keyboard, with a focus on aging effects and differences between dominant and non-dominant hands (Hasegawa, Hasegawa, & Miyao, 2012). Odell studied feedbacks of software keyboards (Odell, 2015). Takei and Hosobe proposed a Japanese kana input keyboard that input 1 character with 2 strokes by using 2×6 keys (Takei & Hosobe, 2018). Yajima and Hosobe proposed a Japanese software keyboard for tablets that reduced user fatigue (Yajima & Hosobe, 2018).

Much research on flick keyboards has been done in Japan. Sakurai and Masui proposed a QWERTY flick keyboard (Sakurai & Masui, 2013). This keyboard enabled input of Japanese kana characters and roman letters without mode changes. Fukatsu et al. proposed an eyes-free Japanese kana input method called no-look flick (Fukatsu, Shizuki, & Tanaka, 2013). This method enabled flick input for vowels and consonants in two strokes. Hakoda et al. proposed a kana input method using two fingers for touch-panel devices (Hakoda, Fukatsu, Shizuki, & Tanaka, 2013). This method was also an eyes-free Japanese input method, but enabled gesture input by two fingers.

Nagasawa investigated, by using questionnaire, how Japanese university students type on smartphones and PCs (Nagasawa, 2017). The result showed that Japanese university students preferred flick input to a QWERTY input whichever of English or Japanese letter input was used. Also, the Japanese Ministry of Education conducted a survey of the information utilization ability of elementary, junior-high, and high school students from 2013 to 2016 ([Japanese Ministry of Education, Culuture, Sports, Science and Technology, 2017]). The results showed that most students were not able to smoothly enter text with keyboards.

Research on display space has been done. Hutchings and Stasko organized a display by creating a small window for managing and displaying related information (Hutchings & Stasko, 2004). Hutchings et al. investigated window management methods for single-monitor users and multi-monitor users by creating a tool that tracked window management events and recorded the window configurations continuously (Hutchings, Smith, Meyers, Czerwinski, & Robertson, 2004). This research was done when the multi-display environment was not popular.

3 PRELIMINARIES

3.1 Japanese Kana Characters

Japanese text is composed of Japanese kana characters and Chinese characters (called kanji in Japanese). While a Chinese character typically has a meaning, a kana character does not; instead, a kana character is associated with a speech sound. There are two kinds of kana characters called hiragana and katakana. Although they are used for different purposes, they correspond to each other; for each hiragana character, there is a corresponding katakana character, and vice versa. In many commonly used Japanese input methods, kana characters are entered with keys, and Chinese characters and katakana are entered with the aid of conversion functions. The method proposed in this paper is the same at this point.

There are approximately 50 basic kana characters, which are further divided into 10 groups that are ordered, each of which typically consists of 5 characters. The first group is special because its 5 characters indicate 5 vowels that are pronounced “a”, “i”, “u”, “e”, and “o”. The other 9 groups are associated with the basic consonants, “k”, “s”, “t”, “n”, “h”, “m”, “y”, “r”, and “w”. A kana character in these 9 groups forms the sound that combines a consonant and a vowel. For example, the 5 characters of the “k” group are pronounced “ka”, “ki”, “ku”, “ke”, and “ko”. This grouping of kana characters is basic knowledge of the Japanese language.

The “k”, “s”, “t”, and “h” groups have variants called dakuon. Specifically, the dakuon variants of “k”, “s”, “t”, and “h” are “g”, “z”, “d”, and “b” respectively. In addition, the “h” group has another variant called handakuon, which is “p”. Certain characters have variants that are written in smaller shapes. Sequences of kana characters can be expressed with the Roman alphabet by using the standard Japanese romanization system (ISO, 1989). This is widely used for computer users to enter Japanese text with alphabet keyboards such as QWERTY.

3.2 Japanese Flick Keyboard

Figure 1 is a standard Japanese flick keyboard. The main character keys are composed of 4×3 key layout. If a user flicks a key to the left, upward, to the right, or downward with a thumb, the keyboard inputs a character corresponding to the direction. The enter key and the delete key are located on the right side of the keyboard. When the “123” or “ABC” key is pressed on the left part of the keyboard, the Japanese keyboard is replaced with the English letter keyboard or the number letter keyboard. A conversion space is located at the top of the keyboard. When a user touches a word, hiragana characters are converted to kanji or other characters. If a user touches the upward arrow, it will show other kanji candidates.

Figure 1: General Japanese flick keyboard (which is implemented on iPhone XS).

4 PRELIMINARY EXPERIMENT

A preliminary experiment was conducted to explore appropriate key sizes, key layouts, and input methods and to estimate user fatigue.

4.1 Method

In this experiment, participants first held a tablet in the portrait mode, operated it freely with two thumbs for some time, and were asked about the feeling of its use. Next, they turned the tablet into the landscape mode, and did the same things. We recruited 6 participants who all were university students majoring in computer and information sciences.

We implemented the keyboard on an ASUS ZenPad 10 tablet (Android OS 7.0, 1920×1200px screen) as shown in Figure 2. The key sizes are 60×60px, and the keyboard is placed symmetrically at the lower ends of the display. The “lowercase convert” key changes the last input character if it can be converted to a lowercase character or a sonant mark. When text is entered, it is displayed on the text field at the top of the display.

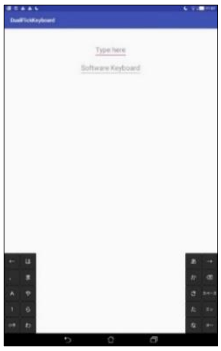


Figure 2: Application used in the preliminary experiment.

4.2 Result

No problems were observed in the key sizes and the input method, but most of the participants found the 5-row key layout inconvenient and felt fatigue because it required long vertical movement of thumbs. Also, participants wanted a function for adjusting the keyboard position.

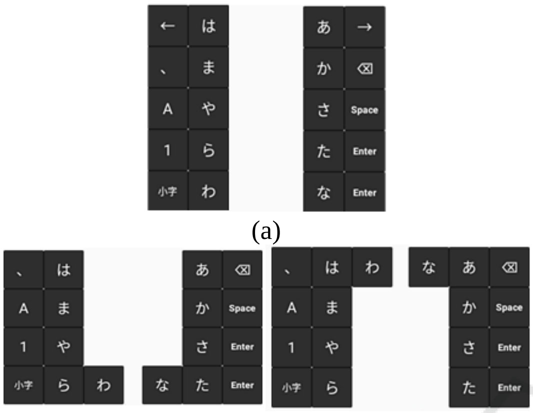
Therefore, we decided to make a keyboard whose position would be adjustable, and also to additionally create an L-shaped layout and a Γ-shaped layout. The keyboard position adjustment function was implemented as a slide bar. We also implemented the function of converting Japanese kana characters to Chinese characters by using an open-source dictionary called SKK.

5 PROPOSED METHOD

This paper proposes a Japanese flick keyboard that reduces display space by splitting the keyboard into the left and the right. It adopts the key layouts shown in Figure 3. As a solution to the problems identified through the preliminary experiment, it introduces an L-shaped layout (Figure 3-b) and a Γ-shaped layout (Figure 3-c) in addition to the initial 5-row layout (Figure 3-a). These 2 new layouts remove the arrows used to change conversions in the 5-row layout.

These layouts enable the effective use of the display because the split keyboards give more display space at the center. Reducing the display space of the keyboard on a tablet can improve the efficiency of the user’s multitasking. In particular, in the split screen mode implemented on Android OS 7.0, display space is important for the user’s multitasking.

The user holds a tablet with both hands, and performs flick input with both thumbs. The character to be entered is displayed above the touched key, and when a thumb is moved to the left, upward, to the right, or downward and is released, the corresponding character is entered. The bimanual input enables smooth input without the user's releasing hands because the user can keep the inputting posture to hold the tablet. Another advantage is that it enables stable input because the user can input while holding a tablet with both hands.



(b) (c)

Figure 3: (a) 5-row, (b) L-shaped, and (c) Γ-shaped key layouts.

The flick input of the proposed keyboard is based on Table 1. Since hiragana basically has five characters in one group, it works well with flick input that uses moving a user's thumb to 4 directions as well as keeping it at a neutral position. If a user flicks a button to the left, upward, to the right, or downward with a thumb, the keyboard inputs the character corresponding to the direction. If the user touches the lowercase convert key, the entered character is converted to the "Lower 1" character in the table. If the user touches the lowercase covert key again, the entered character is converted into the "Lower 2" character if it exists, and into the original character otherwise. "Lower 1" is composed of dakuon and certain characters, and "Lower2" is composed of handakuon and certain characters.

Table 1: Flick input of the proposed keyboard.

Group	Neutral	Left	Up	Right	Down	Lower 1	Lower 2
あ	あ	い	う	え	お	ぁぃぅぇぉ	
か	か	き	く	け	こ	がぎぐげご	
さ	さ	し	す	せ	そ	ざじずぜぞ	
た	た	ち	つ	て	と	だぢづでど	っ
な	な	に	ぬ	ね	の		
は	は	ひ	ふ	へ	ほ	ばびぶべぼ	ぱぴぷぺぽ
ま	ま	み	む	め	も		
や	や	（	ゆ	）	よ	ゃ　ゅ　ょ	
ら	ら	り	る	れ	ろ		
わ	わ	を	ん	ー	@	ゎ	
other	、		。	！	？		

The Japanese kana to Chinese character conversion method is executed by using the conversion space near the right keyboard. When the user swipes this space with a thumb, it displays next Chinese characters, and then the user can tap a word to confirm the conversion. When no character is entered, it displays the top 15 words obtained from the Balanced Corpus of Contemporary Written Japanese (National Institute for Japanese Language and Linguistics, 2015). Thus this space enables inputting frequently used words easily.

6 IMPLEMENTATION

The 5-row layout keyboard (Figure 4-a) has the height of 300px and the width of 120px, the L-shaped and Γ-shaped layouts have the height of 240px and the width of 180px. The 5-row key layout reduces the display space by 70% in the portrait mode and by 81% in the landscape mode, compared with the QWERTY layout keyboard (Figure 4-b) with the maximum display width. The L-shaped and the Γ-shaped layout keyboard reduce the display space by 73% in the portrait mode and by 83% in the landscape mode.

The SKK dictionary of size M was used to convert Japanese kana characters to Chinese characters. The conversion spaces are located on the red parts of Figure 4. The conversion to katakana can be done by swiping the conversion space to the left. In the 5-row and the Γ-shaped layout, the conversion space is located on the left side of the right keyboard. In the L-shaped layout, the conversion space is overlapped with the right keyboard. In this case, when a user touches the conversion space, the processing of the conversion space has a higher priority. The recognition of flick input is done in the same way as usual Japanese flick keyboards.

(a) (b)

Figure 4: (a) The proposed keyboard and (b) the QWERTY keyboard.

Figure 4-b is the QWERTY keyboard created for comparative experiments. This key layout is based on the "ATOK for ASUS" keyboard, but the keys unnecessary for the experiment were not included.

7 MAIN EXPERIMENT

The tablet used in the main experiment was the same as the one in the preliminary experiment. We recruited 10 participants who were Japanese university students majoring in computer and information sciences. The main experiment was composed of two input experiments and subjective evaluation. The subjective evaluation included comments. In the main experiment, participants sat down on a chair and held a tablet with both hands. If participants were not able to reach the center of the keyboard in using the QWERTY, they were allowed to release their hands. The reasons why we selected the QWERTY keyboard for comparison were that there are no popular flick-based tablet keyboards and that split keyboards are not popular in Japan.

The first experiment was the sentence input experiment, and the second one was the word repetition input experiment. For the first and the second experiment, the sentence input speed (WPM_S) and the word input speed (WPM_W) are calculated respectively as follows:

$$WPM_S = \frac{|T| + |E| + 1}{S} \times 60$$

$$WPM_W = \frac{|W| + 1}{S} \times 60$$

where T is the length of the string, W is the length of the word, S is the input time, and E is the number of entered keys after the conversion. The 1's are added to the length of a string or a word to consider the enter key.

For both sentence input and word repetition input, error rates, NCER (which defines the not-corrected error rate) and CER (which defines the corrected error rate) are calculated as follows:

$$NCER = \frac{INF}{C + IF + INF}$$

$$CER = \frac{IF}{C + IF + INF}$$

where C is the total number of correct words, IF is the number of incorrect but fixed (backspaced) words, and INF is the number of incorrect (but not fixed) words. These equations are based on Bi et al.'s research (Bi, Chelba, Ouyang, Partridge, & Zhai, 2012). However, we adjust them to Japanese character input.

After the input experiment, we investigated subjective evaluation. It was composed of comfort, efficiency, etc., with the scales of 1 to 10, and included comments. These items are based on the ones used in Bi et al.'s research (Bi, Chelba, Ouyang, Partridge, & Zhai, 2012) that extended NASA TLX (Hart & Staveland, 1988).

7.1 Sentence Input Experiment

In the sentence input experiment, the phrase set created by MacKenzie and Soukoreff (MacKenzie & Soukoreff, 2003), which was used in Bi et al.'s research (Bi, Chelba, Ouyang, Partridge, & Zhai, 2012), was translated into Japanese and was used.

The main experiment treated both portrait and landscape modes of each keyboard layout. Each input method was carried out for 5 types of sentences. Before the main experiment, participants practiced for a few minutes. They started the experiment by pushing the start button on Figure 4-a, and moved to the next sentence by pushing the enter key. A target sentence was displayed on the text field at the top of the display. The sentences included in the list were about 10-character sentences that mixed Japanese normal kana (hiragana) characters and Chinese characters. The list did not include Japanese katakana characters, numbers, and English letters. The main experiment was performed for the QWERTY keyboard first, the 5-row, L-shaped, and Γ-shaped keyboards in the portrait mode, and then the three keyboards in the landscape mode as well.

7.2 Result of the Sentence Input Experiment

The result of the input speed measurement is shown in Figure 5. The result of analysing WPM_S and error rates with ANOVA did not show a significant difference about NCER and CER, but a significant difference ($p < 0.05$) was shown for the input speed, which means that the proposed keyboard was slower than the QWERTY. In addition, the L-shaped layout indicated the highest WPM_S among the proposed methods. The average error rate became higher because of the following reasons: mistaking a tap of the conversion space, misreading of a target sentence, and partial conversion for correcting unnecessary parts with the backspace key.

(a)
(b)
(c)

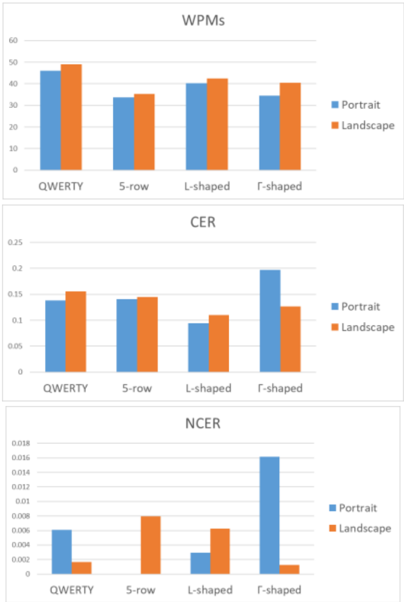


Figure 5: (a) Sentence input speed (WPM_S), (b) corrected error rate (CER), and (c) not-corrected error rate (NCER).

7.3 Word Repetition Input Experiment

The word repetition input experiment used the same layouts as the sentence input experiment. The experiment measured learnability by exploring changes of the speed in inputting the same word 6 times successively. The used words consist of 4 Japanese normal kana characters, possibly including sonant marks.

7.4 Result of the Word Repetition Input Experiment

The result of word input speeds (WPM_W) is shown in. The QWERTY keyboard indicated the highest WPM_W among all the input methods. There were no large differences among the proposed methods. ANOVA showed a significant difference ($p < 0.05$) through the first to the sixth, which means that the proposed method was slower than the QWERTY. ANOVA did not show a significant difference among the proposed methods.

7.5 Subjective Evaluation

Figure 7shows the result of the subjective evaluation. ANOVA showed significant differences ($p < 0.05$) in comfort, accuracy, absence of frustration, and mental demand. Overall preference did not show a significant difference, and there were no large differences among the proposed methods.

8 DISCUSSION

8.1 Sentence Input

In the result of the sentence input experiment, the error rates did not show a significant difference, but the proposed method had a slower input speed than the QWERTY, showing a significant difference. One reason is that the participants needed to more carefully input because of the different key layouts from the standard one. Another reason is that our flick keyboard was split unlike the standard flick keyboard that is composed of 3×4 keys (including punctuation marks and the lowercase convert key).

Large differences did not appear among the proposed methods; in fact, ANOVA did not show a significant difference among the proposed methods. A reason for the differences of input speed between the QWERTY keyboard and the proposed methods is that all the participants were students majoring in computer and information sciences and therefore were good at the QWERTY keyboard. In addition, many of the participants were more used to the QWERTY keyboard than flick input.

In all the methods, the landscape mode was faster than the portrait mode. One reason might be that the portrait mode has longer distances between the input field and the keyboard as shown in Figure 4.

A solution to these problems is to introduce customize functions. In other words, it is necessary to

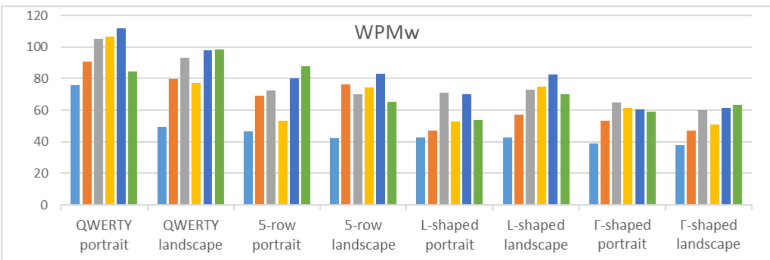


Figure 6: Word input speed (WPM_w).

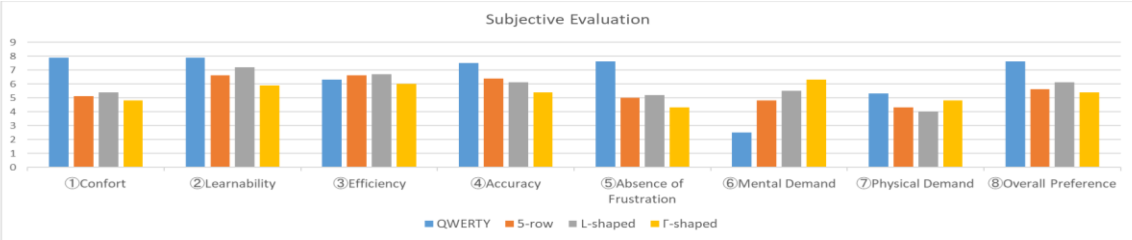


Figure 7: Result of the subjective evaluation. For measures 1-5 and 8, the score of 10 indicates the most positive rating, and for measures 6 and 7, the score of 10 indicates the most negative rating (based on *(Bi, Chelba, Ouyang, Partridge, & Zhai, 2012)*).

enable the customization of keyboards for user's preference. A solution to the problem of inputting string that is far from the keyboard is to display the string near the keyboard or to display a predictive conversion near the input field which is usual on personal computers.

8.2 Word Repetition Input

The word repetition input experiment did not show large differences among the proposed methods in input speed, but ANOVA showed a significant difference between them and the QWERTY keyboard. A reason for the increased misjudgement in continuous input is that flick movement distance decreased. Another reason is that tapping the lowercase convert key failed. The direction was determined by comparing the vertical movement and the horizontal movement. However, when the input direction was upward, a misjudgement occurred because of the sliding of a thumb to the left or to the right. This misjudgement differed in participants, which makes it difficult to solve the problem by using the same configuration for all users. One solution is to introduce a "reform" mode, which adjusts the border of the judgment (e.g., by machine learning) when misjudgement occurs. The problem of tapping the lowercase convert key was unique to the flick keyboard, because the QWERTY keyboard obtained the input of lowercase characters and sonant marks in the same ways as other characters. The usual flick keyboard avoids this problem by using predictive conversion.

8.3 Subjective Evaluation

In the subjective evaluation, ANOVA showed significant differences between the QWERTY and the proposed method in comfort, accuracy, absence of frustration, and mental demand. One reason for the lower evaluation is that the time of the participants' use of the proposed method was short. In this research, the participants used the proposed method for only a few minutes of warming up. In addition, they were fully experienced with the QWERTY keyboard because they majored in computer and information sciences. The mental demand did not show a significant difference among the proposed methods, but the participants got the most tired when they used the Γ-shaped layout. Since the experiment of the Γ-shaped layout was conducted after those of the other input methods, participants possibly confused the key layout with the other layouts.

Although ANOVA did not show a significant difference, the physical demand showed an advantage of the proposed method, which is a common advantage of split keyboards that reduce finger movement.

8.4 Participants' Comments

Comments showed that participants wanted functions for changing key layouts and key positions. In addition, a participant wanted a function for unimanual flick input, together with the current bimanual keyboard. The reason for the changing functions is that the proposed layout differed from the layout of the commonly used flick keyboard. Another reason is that participants needed to use keys on only one side for some words. Participants were satisfied with the slide bar for moving the keyboard position upward or downward, but some participants also wanted to move the keyboard position to the left or to the right in order to fit it to their hands.

There was a comment about the multitap input function for selecting kana characters without flick gestures, which is another common way for inputting kana characters. Although the multitap input function was implemented, the experiment excluded it for the comparison purpose. There were comments about flick input that moving a finger upward or downward caused fatigue, and that flicking to the inside direction was hard to perform in the large display. Also, participants felt fatigue because they were not able to see the keyboard at once in the landscape mode.

There were positive comments of participants. One is that the proposed keyboard will be useful when the participant gets used to it. Another is that the proposed method is more useful than the QWERTY keyboard when the participant holds the tablet in the landscape mode.

9 CONCLUSIONS AND FUTURE WORK

This paper proposed a Japanese bimanual flick keyboard for tablets that improves display space efficiency. In the proposed method, the 5-row key layout reduced the display space by 70% in the portrait mode and by 81% in the landscape mode, compared with the QWERTY keyboard with the maximum display width. The L-shaped and Γ-shaped layouts reduced the display space by 73% in the portrait mode and by 83% in the landscape mode. However, in comparative experiments, the proposed method indicated slower input speed than the QWERTY keyboard.

Future directions include the implementation of customization functions, a predictive conversion function, and a function for setting the multitap input. Since the result of the experiment suggested it is necessary to implement functions for setting up appropriate keyboards for different users. There is room for improvement in experiments. For example, the usage time of the proposed method was much shorter than the QWERTY keyboard. It was a main cause for the difference of the experimental results. Also, it is necessary to increase the number of keyboards to be compared. For example, the above-mentioned problem might be reduced by using an input method based on a flick keyboard or other input methods that are less familiar to the subject than the QWERTY keyboard.

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