ABSTRACT
Chinese text entry solutions for mobile phones are critical, since they get used by most Chinese mobile phone users every day. We designed two new solutions for Chinese pinyin text entry with a rotator as input device. They were evaluated in an empirical study with 12 novice users and compared to a straightforward implementation of the date stamp method. Although there was no significant difference between the three designs on user performance, the perceived efficiency by users was higher for one of the new designs, and it was their technique of choice for their own phone. Because the evaluation setup favored the date stamp method (it was the only one supporting predictive input, and also the most familiar to users), the results are encouraging. We close by discussing how to further develop the new techniques.

Categories and Subject Descriptors
H5.2. [Information interfaces and presentation]: User Interfaces -- Input Devices and Strategies, Evaluation/methodology, Interaction Styles.

General Terms
Performance, Design.

Keywords
Chinese, pinyin, mobile phone, rotator, text entry, input.

1. INTRODUCTION
There are currently more than 500 million mobile phone users in mainland China. Most of them use short message services (SMS): about 41 billion SMS messages were sent by mainland Chinese mobile phone users in January of 2007 [16]. Hence phone products need to provide easy-to-use Chinese text entry solutions to support the high penetration of mobile phones and SMS among Chinese users.

Chinese text entry solutions consist of three key elements: input device, input method and input features, which are also key areas for innovations [9].

Many novel input devices, for example the reduced QWERTY keyboard [4], or novel input technologies like touch technologies [1, 20], have been studied or proposed for mobile devices. The 12-key keypad (Figure 1) is still the dominant input device because of its familiarity, and also because its compact size is suitable to be held and used with one hand.

Figure 1. The 12-key keypad
As a non-alphabetic, logosyllabary language [18], Chinese cannot be input directly with devices like the Roman keyboard. Two fundamental coding systems to represent thousands of Chinese characters with limited keys in the keyboard have been developed: by pronunciations and by stroke structures [6, 17]. Text entry methods are based on the coding systems. The methods based on pronunciations are easier to migrate across input devices than those based on stroke structures.

Pinyin is a standard coding system based on Mandarin pronunciation of Chinese characters in the form of roman letters [2, 18]. Most pinyin marks consist of a consonant and a vowel while some just have a vowel. For example, the pinyin mark of “中” is “zhong”. “Zh” is the consonant and “ong” is the vowel. The pinyin coding system together with an input device and relevant input features form a Chinese pinyin input solution. Keyboards are the most common input devices to be combined with pinyin. Pinyin coding is currently the most common text entry method both for personal computers and for mobile phones by mainland Chinese users.

Entering a Chinese character with pinyin coding on a mobile phone typically consists of three key steps. First, users need to type the pinyin mark by pressing the keys on the phone – in the...
example above, five keys are pressed: the keys for “z”, “h”, “o”, “n”, and “g”. Second, users need to select the target pinyin mark for the character because a series of key presses on the 12-key keypad may result in more than one pinyin mark (when the multi-tap method is not used). Third, users need to choose the target character from options provided by the input engine. That is because most Chinese characters are homophonic with some others and a pinyin mark usually corresponds to multiple Chinese characters. The number of corresponding characters for different pinyin marks ranges from only one to more than twenty. The average number of corresponding characters for all pinyin marks is about 16.8 \[21\]. Figure 2 shows the input process of pinyin with the 12-key keypad.

![Figure 2. Pinyin input process with the 12-key keypad](image)

Many pinyin based text entry solutions enable users to complete a pinyin mark by entering its consonant and vowel. An example is the Shuang Pin (Double Spelling) method designed for QWERTY keyboards [14]. In Shuang Pin, all the consonants and vowels including more than one letters (such as “zh”, “ch”, and “ong”) are mapped to a certain key on the keyboard. For example, “zh” (a consonant) and “ong” (a vowel) are mapped specifically to the keys “a” and “y” on the keyboard. Users just need to type “a” and “y” to complete “zhong”. The method requires fewer key strokes; however, it requires users to memorize the key mappings. The Double Spelling soft keyboard in, for example, Windows CE systems [15] includes a consonant keyboard and a vowel keyboard. Consonants and vowels are presented to end users separately and users need to complete a pinyin mark by typing the needed consonant and vowel in the two keyboards. With the method, users do not need to remember any key mapping, but to get familiar with the two keyboard layouts needs practice. The Double Spelling method is implemented in many pinyin text entry solutions as a complement to the normal pinyin method.

Input features are the functions enhancing the core text entry method that are customized according to the input device and method in order to make text entry and edition easier and more adaptive. For example, phrasal input was recently adopted by many text entry solutions in mobile devices [9]. We will not describe the stroke method and input features in the paper as they are not the focus of our research.

In the past few years innovations and ideas on input devices have emerged mainly in the field of direct operation, for example, touch technologies [1]. We designed and evaluated Chinese pinyin text entry with a rotator input device, also called a wheel in some other studies [13]. A rotator is a ring or round device that can be rotated in both clockwise and anticlockwise directions. The rotation is mapped to operations on displayed objects. The rotator enables two operations: rotating and clicking. The corresponding operations on displayed objects are scrolling and selection. The rotator has been implemented as a key input and navigation device in some mobile products including Nokia 7280 and Dopod P800W. Figure 3 shows the rotator on the Nokia 7280 as the main input device (called a “spinner” by Nokia).

To enter text in languages that use the Roman alphabet, users can first scroll in a list of characters displayed on screen by rotating the device and then select the target character by clicking it. Clicking can be implemented either using the rotator itself (for example, the center of the rotator in Figure 3 or the edge of it can be pressed), or by another dedicated key.

![Figure 3. The rotator in Nokia 7280](image)

Several past studies have examined selection-based text entry solutions that use screen real-estate to display the selectable objects. Various devices have been utilized in the studies. MacKenzie proposed a three-key (Left and Right arrow keys and a Select key) date stamp method and found its input speed to be about 9 to 10 words per minute (WPM) with novice users [10]. Tarasewich suggested a similar method but used the thumbwheel located at the top of the left-hand side of the Sony Clie PEG-S320 [19]. Wobbrock, Myers, and Aung studied the use of a joystick with the EdgeWrite method and compared its user performance with two selection-based methods [22]. In the above selection-based text entry solutions, a common layout for characters was the so-called date stamp method, where all the characters from “a” to “z” were listed either in alphabetical order or in a fluctuating optimal character layout [10]. In our initial design for Chinese pinyin input with a rotator, we also used the date stamp layout.

Only a few empirical studies exist on rotator-based input solutions. Proschowsky, Schultz, and Jacobsen designed a text entry method called TUP with touch sensitive wheels and compared its user
In this paper we first describe the initial design of the pinyin input method with a rotator, we did not expect a better user performance than that of current keypad input methods. However, the feasibility and potential to be a good device for text entry and navigation was worth exploring. In particular, because the rotator seems good for navigation tasks and selecting target pinyin marks and Chinese characters from options provided by the system are necessary steps in the pinyin-based input methods, it might work better together with Chinese pinyin input than with Roman languages. Wang, Zhai, and Su have conducted an anatomical study of text entry with the pinyin method and found that the character selection process can cost more than half of the time in the whole process [21]. They used keyboard and eye-gaze as input devices; the situation can be worse with the ITU-T keypad on current mobile phones.

In this paper we first describe the initial design of the pinyin input method with a rotator (called “rotator pinyin input” in the sequel, for short). We also present the findings of a quick user evaluation. Second, we describe two variations of the initial design, expected to yield improved usability, and their design principles. Third, we present an empirical study to compare the three designs based on performance and subjective preference. Finally, we discuss the findings, present the conclusions, and outline future work.

2. INITIAL DESIGN AND QUICK USER EVALUATION

The initial design was a combination of a rotator and the alphabetical layout of characters in the date stamp method. Figure 4 shows the user interface for rotator pinyin input. The rotator can be turned in both directions and is also clickable. To start text entry with the rotator, users need to click the rotator (or the pen key on Symbian S60 phones, for example Nokia 3650) to activate the input frames on the phone display. There are three input frames on the display.

- The letter frame, where the 26 Roman letters, some punctuation marks (comma, period, question mark and exclamation mark), a space for focus change and input modes (pinyin, stroke, English, number, symbol) are listed.

- The pinyin frame, where all matching Chinese characters are presented as options.

In the initial design, users scroll in the letter frame with the rotator and select the target letter by clicking it. The selected letters are displayed in the pinyin frame in real time. After a pinyin mark is complete, users can select the space key in the letter frame to move the display focus from the letter frame to the Chinese character frame so that they can scroll in the latter to select the target character. To change focus back and make corrections on the entered pinyin marks (if needed), users can click the clear key. To input text in other than Chinese characters like Roman characters, punctuations, numbers or symbols, users just need to scroll in the letter frame and select the correct input mode.

The initial design also integrates predictive input on both the pinyin level and the character level to make the input faster. After users enter a letter of a pinyin mark, the input engine will predict and list possible following letters in the letter frame automatically. On character level, once users enter a Chinese character, the input engine predicts the next possible character based on the phrase corpus embedded in it. All the predicted Chinese characters are presented in the Chinese character frame and users can select the target one right away. The initial design for rotator pinyin input copied the user interface for rotator English input in many aspects.

We conducted a quick user evaluation on the initial design to check if the user interface was easy to learn. We found that almost no users could discover how to switch the focus between the letter frame and the character frame. Although some users could find it, the means for the focus change dramatically hindered the input process and made it less smooth. Improving the method for focus change can enhance the usability of the rotator pinyin method.

We also observed that users did not realize that the rotator was clickable, but once they knew it, they accepted it well. Another observed common problem was that click of the rotator sometimes did not result in selection of the focused item; instead, focus had moved to the following item at the time of clicking. This mix of clicking and rotating raised the question of whether the rotator is a proper device for a selection task. It might be safer to map the selection function to another key.

These considerations led us to the new designs described in the next section.
3. NEW DESIGNS
The key motivation for the new design ideas was that the focus change was too difficult in the initial design in terms of both discoverability and input efficiency. Would it be possible to change focus automatically between the letter frame and the Chinese character frame? As described above, most pinyin marks consist of two parts: a consonant and a vowel. Moreover, pinyin marks always end with a vowel. Hence, another natural solution is to present consonants and vowels in two lists and let the users complete a pinyin mark by simply combining the two selections. What is more, focus can automatically change from the letter frame to the Chinese character frame once a vowel is entered. We will call such a design the consonant plus vowel solution.

The new design may also bring extra benefits by improving input performance. In [21], it was mentioned that “On average, each Chinese character’s pinyin has 4.2 Roman characters.” The result means that on average, with the initial design users need to rotate and select in the letter frame more than four times to complete a pinyin mark. However, the result might not applicable to Chinese SMS messages, so we computed the average number of Roman characters for all pinyin marks based on a Chinese SMS corpus. In total, the corpus consists of 630k of SMS messages or 9.2M Chinese characters (where punctuations have been ignored in the statistics). In this extensive corpus, the average number of Roman characters per pinyin mark is considerably smaller: only 3.24. Moreover, if we take into account the frequencies of the Chinese characters, the figure drops to 2.88. Nevertheless, with our new design users just need to rotate and select twice to complete a pinyin mark. The decrease in navigation and selection time could help to improve user performance. But on the other hand, the consonant and vowel solution has a longer vowel list, which is about twice as long (in screen size) as the normal Roman alphabet. Table 1 shows all the consonants and vowels of pinyin. An empirical study is needed to verify the possible improvement brought by the new design.

<table>
<thead>
<tr>
<th>Consonants in the phonetic order (initials)</th>
<th>b p m f d t n l g k h j q x zh ch sh r z c s y w</th>
</tr>
</thead>
<tbody>
<tr>
<td>23 consonants</td>
<td></td>
</tr>
<tr>
<td>33 vowels (finals)</td>
<td>a e i o u v(u) ai an ao ei en er ia ie in iu ou ua ui un uo eng ian iao ing ong uai uan iang iong uang</td>
</tr>
</tbody>
</table>

In the new designs, the rotator is still clickable for selection. There are still only two frames (letter frame and Chinese character frame) on the display, but the contents of the letter frame alternates between phonetic consonants and vowels, depending on the phase of creating the pinyin mark.

We provided two ways to switch focus between the letter frame and the Chinese character frame. One is the automatic focus switch. Once users input a vowel to complete a pinyin mark, the focus is automatically changed from the letter frame to the Chinese character frame. Similarly, once users select the desired Chinese character, the focus is automatically changed from the Chinese character frame to the letter frame for entering the next character. Another way is to select the functional items in the frames. To change focus from the letter frame to the Chinese character frame, users can select the “confirm” (“确认”) item in the letter frame. To switch the focus from the Chinese character frame to the letter frame, users can select the “go back” (“返回”) item in the very beginning of the Chinese character frame.

For those pinyin marks consisting of a single vowel, we added a functional item as “vowel” (“拼音”) in the letter frame and users can directly go to vowels by selecting it. The often used punctuation marks (comma, period, question mark and exclamation mark) and the input modes (pinyin, stroke, English, number and special characters) are also listed together with the consonants in the letter frame.

Figure 5 illustrates the input process step by step. In the top left corner, the user begins entering the pinyin mark. The letter frame shows the phonetic consonants in the phonetic order. The user scrolls to the right and eventually selects the letter “t”. Then (in the top right corner) the letter frame automatically changes to display the phonetic vowels, in order of increasing length. In the bottom left corner the user has scrolled in the vowel list far enough to be able to select the ending (“ong”) of the pinyin mark (“tong”). After selection (bottom right corner), focus switches to the Chinese character frame, where the user can again scroll to select the desired character.

Predictive input on both pinyin mark and Chinese character levels are applicable to the new design. In many pinyin marks, some vowels can never come after some consonants. And predictive input at the pinyin mark level can increase input speed of the new design because the vowel list would not be that long. However, for implementation reasons predictive input on the pinyin mark level was not included in the versions that were tested empirically. Predictive input on character level works so that after a character is entered, the most likely characters that could form a phrase together with it would be presented for users to select. In that way, users would not need to input pinyin marks for the later characters, but just select them. However, the predictive input on the character level brings an obstacle for fully automatic focus switch. For example, if users could not find a target from the predicted character list, they would have to manually switch the focus from the Chinese character frame to the letter frame to enter it. Thus two ways of focus switch are provided for the new design.

There are basically two ways to present consonants in a list: the alphabetical order and the phonetic order. The alphabetical order is to list consonants according to the order of their first letter in the Roman alphabet. Figure 6(a) shows the pinyin consonants in the alphabetical order. The phonetic order is the one Chinese primary school students are taught when they start to learn pinyin and Chinese characters. Table 1 shows the pinyin consonants in the phonetic order. There are also two ways to list vowels: the alphabetical order and the length order. The alphabetical order means all vowels are listed according to the order of their first letter in the Roman alphabet. Figure 6(b) shows the vowels in the alphabetical order. The length order means the vowels are listed according to their length. For vowels that have the same length, their order is decided by the alphabetical order of their first letter. Table 1 shows the length order.
For user evaluation we built the following two prototypes.

3.1 Alpha: New Design 1
In this design, both consonants and vowels are listed in the alphabetical order as shown in Figure 6. The alphabetical order was assumed to be familiar to many users and the consistency between the consonant list and the vowel list should help users to understand the design.

3.2 Beta: New Design 2
In the Beta solution, the consonants are listed in the phonetic order and the vowels are listed according to their length. We implemented this design because of two reasons: 1) we assumed the phonetic order could remind users about the consonants and vowels of pinyin marks so as to help users to understand the design, and 2) we assumed the length order of vowels could provide a good visual cue on where to find the needed vowel.

4. USER EVALUATION

4.1 Objectives
Both the Alpha and Beta solutions had some performance advantages over the initial design because of the following reasons:

- On the average, users need to scroll and select around 4 (2.88 Roman characters plus a confirmation) times to complete a pinyin mark with the initial design but with the new designs, the number is 2.
- Focus switches are automatic, which also decreases the number of scrolling and selecting actions.

However, there are also factors that might offset the advantages brought by the two factors mentioned above. First, predictive input on pinyin level was missing for both Alpha and Beta while the predictive input was fully implemented in the initial design. Second, the vowel list had to be longer (in the screen size) than the list in the initial design due to the absent of predictive input on pinyin level. On the other hand, the dimensions of a character on the screen are not really important – the length of the list that needs to be scrolled is, because the number of items directly corresponds to the motor movement of the rotator.

We will discuss the effect of missing prediction capability after presenting the test results.

To verify the assumptions with facts, we designed an empirical study whose objectives were:

- to check if the automatic focus switch helps,
- to collect further usability problems of the initial design, Alpha and Beta as Chinese rotator pinyin input solutions,
- to compare user performance of the three designs, and
- to collect information on user preference and comments on the three design solutions.

4.2 Method

4.2.1 Participants
12 volunteers, 7 males and 5 females, aging from 21 to 35, participated in the user evaluation. 5 participants were familiar with the Symbian S60 user interface. All were right handed and daily users of the keypad pinyin input method (T9) in their mobile phone. All were first-time users of the rotator.

4.2.2 Apparatus
Figure 7 shows the prototype built on Nokia 3650 and the testing environment. Participants just needed to hold the phone prototype to complete the evaluation sessions. The phone prototype was connected to a laptop computer via a sharp box. All inputs by the rotator from the phone were transferred to the computer via the box. The computer, with the input engine, fed back the proper output on both the computer display and the phone prototype.

We recorded the test sessions with two video recorders. One camera was attached to the phone prototype to record the phone display and the user interactions. The other video camera was used to record the user.
4.2.3 Tasks and materials
The participants completed two text entry tasks with all three designs. The first task was for diagnostic purposes and the second one was to collect user performance data. In the second task, the participants were asked to enter the messages exactly as they were presented on paper, which meant that they needed to correct any errors they did in the input process. We also instructed the participants to enter the texts in the second task as accurately and quickly as they could. The messages used in both tasks were real short messages that we collected from end users in past studies (see Table 2). All characters in the messages belonged to top 500 frequently used Chinese characters. For task 2, the average pinyin lengths for the two sentences are respectively 3.1 and 3 letters.

<table>
<thead>
<tr>
<th>Task</th>
<th>Message</th>
<th>Pinyin</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Please input the following message: 我乘坐MAS 613航班9：48到达。</td>
<td>wo cheng zuo MAS 613 hang ban 9:48 dao da (average pinyin length: 3.1)</td>
<td>I will arrive at 9:48 by flight MAS 613.</td>
</tr>
<tr>
<td>2.</td>
<td>Please input the following messages: 1.明天下午两点同学聚会，你能否和我一同参加？2.今晚不回家吃饭了，十点左右到家。</td>
<td>ming tian xia wu tong xue jhui, ni neng you he wo yi tong can jia? (Average pinyin length: 3.1)</td>
<td>1. There is a party for classmates at 2 pm tomorrow. Could you go to it together with me? 2. I cannot have my dinner at home today, and I will arrive home at about 10 pm.</td>
</tr>
</tbody>
</table>

4.2.4 Experiment Design, Procedure and Measures
Every participant needed to complete both tasks with all three design solutions. The order of input methods was counterbalanced.

Before the evaluation started, we introduced the objectives of the evaluation emphasizing that the evaluation was on our design solutions instead of participants themselves. Then participants were instructed to fill in a pre-evaluation questionnaire for profile collection. After that the test session started in which the participants entered the messages with the three methods. After completing the tasks with each method, the participant gave a subjective evaluation with 5-point Likert scale questionnaire. Finally, participants were asked to choose one design that they would like to have in their own mobile phone.

When analyzing the results, we counted the number of “clear” operations (the number of times the “C” key on the mobile phone was pressed) by each participant in the second task and computed their input speed in characters per minute (CPM) [11]. We also collected subjective scores on understandability and perceived performance of the design solutions. Understandability scores indicate the walk-up usability of the design solutions and the perceived performance scores indicate the subjective perceptions and feelings of system performance, which is relevant for feasibility of take up of the method in the long term.

4.3 Results
4.3.1 Observation results
In general, the participants had no problem in understanding the initial design. All of them also quickly got the idea of “consonant plus vowel” with Alpha. But since in Beta the vowels visible in the first screen (see the second step in Figure 5) are the ones with only one letter, it took a while for all the four participants, who started the evaluation with it, to get the idea of “consonant plus vowel”.

8 participants discovered that the rotator was clickable. All the participants mastered it quickly after they knew it. No participant discovered that pressing the pen key can also activate the frames on the display. We informed the participants of this option, but they forgot it again during the input process.

All participants easily accepted and mastered that pressing the rotator can select an item in the frames. No participants had problems in changing input modes with the rotator. Some participants noticed that the list in the letter frame was a looping one and they rotated both in clockwise and anticlockwise directions to enter text faster.

Automatic focus switch was implemented in all designs. Some single letters, for example “g”, can also indicate the ending of a pinyin mark, and we applied this principle, too, in the initial design. All participants used both automatic and manual focus switching. However, we observed clear hesitation before participants rotated to the functional items for focus switch and selected them: the participants seemed more attentive in such cases. Moreover, since sometimes the automatic focus switch was on and sometimes it was off depending on the input conditions, participants were observed to be a bit confused with the inconsistency.
4.3.2 Performance results
Table 3 shows the number of clear operations in the second task by all participants for error correction. Participants seldom made serious errors with rotator input: on the average, there were two clear operations per user for Alpha, one and a half for the initial design, and only one for Beta. We observed that participants sometimes passed targets and had to rotate back, but that could be corrected by navigation and did not introduce any errors or clear operations. ANOVA test indicated that the main effect of design solution on error frequency was not significant (F2,35 = 1.36, ns).

Table 4 and Figure 8 show results on input speed with all design solutions. As Figure 8 shows, there was no uniform pattern for all participants. Some participants (3, 7, 9, 12) were faster with the initial design, some others achieved higher input speed with Alpha (1, 2, 4, 8, 10) and the rest were faster with Beta (5, 6, 11). On the average, participants achieved the highest input speed with Alpha, followed by the initial design and Beta. ANOVA indicated that the difference was not significant (F2,35 = .37, ns).

Table 3. Number of clear operations by each participant

<table>
<thead>
<tr>
<th>User no.</th>
<th>Initial</th>
<th>Alpha</th>
<th>Beta</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 4. Input speed and ANOVA test results

<table>
<thead>
<tr>
<th>Variable</th>
<th>Design Solution</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial Alpha</td>
<td>Beta</td>
<td></td>
</tr>
<tr>
<td>Input speed (CPM)</td>
<td>6.46</td>
<td>6.56</td>
<td>6.17</td>
</tr>
<tr>
<td></td>
<td>1.05</td>
<td>1.28</td>
<td>1.11</td>
</tr>
</tbody>
</table>

4.3.3 Results of subjective evaluations
Table 5 and Figures 9, 10 and 11 show the results from the subjective evaluations. Participants thought the initial design was the easiest to understand, followed by Alpha and Beta. ANOVA indicated that the main effect of design solution was significant (F2,35 = 17.64, p < .01). Further t-test showed that the difference between any two design solutions was significant.

Table 5. Subjective evaluation results on understandability and perceived performance

<table>
<thead>
<tr>
<th>Variable</th>
<th>Design Solution</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial Alpha</td>
<td>Beta</td>
<td></td>
</tr>
<tr>
<td>Understandability</td>
<td>4.83</td>
<td>4.17</td>
<td>3.00</td>
</tr>
<tr>
<td></td>
<td>0.39</td>
<td>0.84</td>
<td>0.95</td>
</tr>
<tr>
<td>Perceived performance</td>
<td>2.83</td>
<td>3.92</td>
<td>3.08</td>
</tr>
<tr>
<td></td>
<td>1.03</td>
<td>0.79</td>
<td>0.90</td>
</tr>
</tbody>
</table>

As Table 5 shows, participants thought they could achieve the best performance with Alpha, followed by Beta and the initial design. ANOVA indicated that the main effect of design solution was significant (F2,35 = 4.63, p < .05) and further t-test indicated that scores for Alpha were significantly higher than those for the other two designs.

Figure 9. Subjective evaluation results on understandability of all design solutions (the darker the color, the higher the score)

Figure 10. Subjective evaluation results on perceived performance

Figure 11 shows which design the participants would choose for their own mobile phone. Two of the 12 participants liked both the
initial design and Alpha, but not Beta. The other 10 participants chose just one as the most preferred solution. 7 of them preferred Alpha, 1 chose the initial design and 2 chose Beta.

Figure 11. User preferences on design solutions

5. DISCUSSION

Although a rotator is not a direct input device like a keyboard, it has some advantages. First and foremost, it is very good for navigation, and it supports selection as well. This means that the rotator is alone sufficient for some simple interaction tasks. In particular, it is a tempting choice for text entry in languages that have a larger character set than the keyboard can hold, and where the production of each character therefore inherently requires navigation and selection. Moreover, users do not need to move their fingers among different components of the input device, which is a potential source of improvements in operation efficiency. Finally, the rotator can be used on devices that are so small that they cannot accommodate even a normal ITU-T keypad.

Based on the initial design of Chinese pinyin input with a rotator, we provided two new design solutions which were based on the idea of “consonant plus vowel”. The empirical research results showed that there is no significant difference among the three designs on user performance. An interesting question is how much the prediction helped in the initial design. The time per character entered consists of two parts: length of list to be scrolled, and number of selections. Prediction does not affect the latter. Table 6 shows the number of each type of operations in each of the cases.

Table 6. Number of operations for entering the test sentences

<table>
<thead>
<tr>
<th></th>
<th>Scrolling distance</th>
<th>Selections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial, without prediction</td>
<td>1097</td>
<td>119</td>
</tr>
<tr>
<td>Initial, with prediction</td>
<td>652</td>
<td>119</td>
</tr>
<tr>
<td>Alpha</td>
<td>979</td>
<td>78</td>
</tr>
<tr>
<td>Alpha, with prediction</td>
<td>694</td>
<td>78</td>
</tr>
<tr>
<td>Beta</td>
<td>970</td>
<td>78</td>
</tr>
<tr>
<td>Beta, with prediction</td>
<td>695</td>
<td>78</td>
</tr>
</tbody>
</table>

Thus we see that prediction shortens the navigation by about 30% in the initial design, and in the predictive version most of the navigation is taken by entering the first Roman letter of the pinyin mark. In Alpha and Beta, on the other hand, the number of selection operators is only about 65% of that in the initial design. This explains well why the differences balance out, and no significant time difference was found in the test.

We also see in Table 6 that if prediction had been implemented for Alpha and Beta, their motor performance should have been almost equal. Moreover, they do not lose much to the date stamp method in scrolling distance, and therefore the number of selection operations becomes the decisive factor. Here the difference is the same as without prediction, i.e., clearly favoring Alpha and Beta over the date stamp method.

The published input speeds for the Chinese pinyin method with the 12-key keypad vary a lot. Lin and Sears reported that the input speed of a pinyin method with the 12-key keypad is about 5.5 CPM in 2005 [7]. However, the authors didn’t specify the context and methods used in the experiment. Liu and Wang reported that the Chinese pinyin phrasal input with the 12-key keypad can enable users to reach an average input speed up to 34 CPM although some other phrasal pinyin input methods can just get an average speed of 14 CPM [9]. This increase in input speed could happen because Chinese users are getting more and more familiar with the mobile device and more advanced features and technologies are developed. Thus we believe 6 to 7 CPM for rotator Chinese input method is already a good start for a method that does not use character level prediction.

The two designs aim to promote usability of the rotator Chinese input by enabling the automatic focus switch. However, it did not help as much as we expected. Both automatic focus change and manual change were used with all three design solutions. In some conditions, users had to manually select the functional items in frames to switch the focus. For example, if users could not find the target character in the predicted Chinese character list, they had to change focus from the Chinese character frame to the letter frame manually. On the other hand, sometimes they did not enter the full pinyin mark when they noticed that the needed character had already appeared in the Chinese character frame. Then they would stop creating the pinyin mark and change the focus to the Chinese character frame to select the character.

New designs on focus change are still needed. Automatic focus change worked in some cases but not always. The inconsistency confused some users and required more attention. We observed that the focus change possibilities provided made the input process less smooth with Alpha and Beta. Two techniques might help with this. One is to introduce dedicated keys for the focus change: using them might become automatic after a period of practice. Another possibility (only for Alpha and Beta, which use phonetic characters) is to remove the inconsistency by giving up predictive input and ask users to input characters one by one. In such a case the focus could always be switched automatically between the letter frame and the Chinese character frame.

Subjective evaluations are usually more sensitive than performance results as indicated in many past studies [3, 5]. In our study user performance results did not show improvements of Alpha and Beta compared to the initial design, but the subjective results showed that users believed they could perform better with Alpha than with Beta and the initial design. Many participants commented that they thought the “consonant plus vowel” approach would decrease the number of scroll and selection actions. When comparing Alpha with Beta, many users commented that (contrary to our expectations) they were not
familiar with the phonetic order of consonants in Beta, which then led to worse performance.

As the subjective results showed, the initial design was the easiest to understand for novice users. Alpha also got an average score above 4, which indicated that it, too, was easy to understand. However, Beta got a neutral score. The result was compatible with what we observed in the evaluations. In addition to the problems caused by unfamiliarity with the phonetic order of consonants, the start of the vowel list consists of only single-letter vowels, and users did not realize the list continued beyond what was visible on the first screen.

When choosing the overall preferred design, 9 out of 12 users voted to choose Alpha. Users seem to value perceived performance of a design solution over immediate understandability.

6. CONCLUSIONS
We designed two new solutions, Alpha and Beta, for Chinese pinyin input with a rotator, and conducted an empirical study to compare them with novice users. The results indicated that although there was no significant difference between the three design solutions on user performance, users believed that they could achieve better performance with Alpha than the other two solutions, and chose it as their preferred input technique.

This is a promising result, because the test setup favored the traditional design. No predictive input was implemented for the new designs. Also, all test participants were novices in using the rotator as an input device; it is reasonable to expect that in a longitudinal study the advantages of the new techniques, which require a smaller number of selections, would become more pronounced. In spite of this, the differences in performance between the traditional and new methods were small (not statistically significant). This shows that the techniques presented have potential to be further developed into an efficient pinyin text entry technique with a rotator.

7. ACKNOWLEDGMENTS
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8. REFERENCES