Design of Smartphone 9-Key Keyboard Based on Spelling Rule of Pinyin

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Abstract. Currently, the layout of the smartphone 9-key keyboard is that 26 Latin letters are sequentially distributed on the 1st to the 9th keys according to the alphabetical order, which is irrelevant to the spelling rule of pinyin. This paper, based on the study and conclusion of the spelling rule of pinyin, designs a layout mode of the 9-key keyboard that can meet the Chinese input demand by combining the analysis of usability of different areas of the smartphone interactive interface. Moreover, the new layout mode is compared with the existing keyboard layout by comparing the finger movement distance during Chinese input, and the Chinese input efficiency of the new layout mode is verified. This paper provides new possibility for realizing diversification of the human-computer input interface of the mobile terminal in the future and better meeting the demand of Chinese input users, especially the elderly users.

Keywords: Pinyin · 9-key keyboard · Human-Interaction design
Chinese input · Input efficiency

1 Introduction

The existing keyboards of smartphone platforms with Chinese input include the 26-key keyboard (the full keyboard) and the 9-key keyboard. Each keyboard contains 26 Latin letters, and the layout is shown as follows.

Compared with full key input, the 9-key keyboard is a more frequently-used keyboard input mode [2, 3], mainly due to its good fault tolerance. Compared with the 26-key keyboard, the number of keys of the 9-key keyboard is smaller, so each key has a bigger occupation in the same sized mobile phone screens. Taking the iFly input keyboard of the iOS 10 system of the 4.7-in (diagonal line) iPhone 7 as an example, the size of a key of the 26-key keyboard is 4.9 mm*6.7 mm while that of the 9-key keyboard can be as large as 12.7 mm*8.5 mm, as shown in Fig. 1. According to the study data of the MIT laboratory, the average fingertip size is 8–10 mm [4], and key operation is generally not simple fingertip touch. Therefore, the large key area ensures that the 9-key keyboard has better fault tolerance, because users can see the keys more clearly and avoid misoperation easily. This feature of the 9-key keyboard is important for the elderly users with poor eyesight and users with thick fingers, and it is also the reason why the 9-key keyboard is more suitable for the smartphones with small sized screens.

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iFly pinyin 9-key keyboard of ios   iFly pinyin 26-key keyboard of ios

Fig. 1. 9-key keyboard and 26-key keyboard [1]

However, some problems still exist in the layout mode of the 9-key keyboard:

The Layout Does Not Reflect the Spelling Rule of Pinyin. In the 9-key keyboard, the 26 Latin letters are distributed on the 1–9 keys in the sequence of A, B, C, D, E, F, G, H, I, J, K, L, M, N, O, P, Q, R, S, T, V, U, W, X, Y and Z. This layout ignores the spelling rule of pinyin. For example, for users [5] of small sized mobile phones and accustomed to operating with one hand, the letter V with a small use frequency in Chinese input appears in the key within the comfortable operation area of the mobile phone interface, while the letter N with a high use frequency is put in the key within the operation area difficult to operate. Considering the large difference between pinyin input and English input, this keyboard layout mode has obvious limitation for Chinese input and influences the input efficiency during human-computer interaction.

The Existing Layout Mode has no Function of Initial Associating Inputting. When using the 26-key keyboard, users can input common word groups simply by inputting initials. For example, to input “到处 (daochu)”, users only need to input initials D and C and then choose the word group “到处 (daochu)” from the options. However, the initials and the finals are always on the same key in the 9-key keyboard. For example, both the final A and the initials B and C are on key 2, and both the final E and the initials D and F are on key 3. Thus, the 9-key keyboard does not support fast associating inputting through initials like the 26-key keyboard in most cases.

In sum, the 9-key keyboard has better operation fault tolerance due to its large key area and it is more suitable for the smartphones with small sized screens. However, the existing layout of pinyin letters of the 9-key keyboard does not take the spelling customs of pinyin into full consideration. With the development of the human-computer interaction technology, it is certain that the keyboard design will break through limitation of the existing mode and provide more diversified selections for different customer demands, thereby improving the human-computer interaction efficiency and user experience. Thus, based on consideration of the use rules of pinyin and the human-computer interaction comfortableness, this paper designs a 9-key keyboard layout mode that can meet the Chinese input demand, hoping to improve the Chinese input efficiency and meet the demand of the elderly users and Chinese users.

2 Research Method

(1) Summarization and conclusion of the spelling rule of pinyin: functions of different letters of pinyin were analyzed, and the letters were divided into groups according to the functions.
(2) A new letter layout mode of the 9-key keyboard for Chinese input was designed based on the above rule by combining the human-computer interaction operation hot area.
(3) Human-computer interaction efficiency verification: based on the general method of keyboard efficiency verification, this study built a distance matrix according to the finger movement distance of the operator, and compared the new letter layout mode and the existing layout mode, so as to verify whether the human-computer interaction efficiency is improved during Chinese input.

3 Study of Spelling Rule of Pinyin

3.1 Use Frequency of Pinyin Letters

Figure 2 shows statistics of the use frequency of pinyin letters. According to the statistics table:

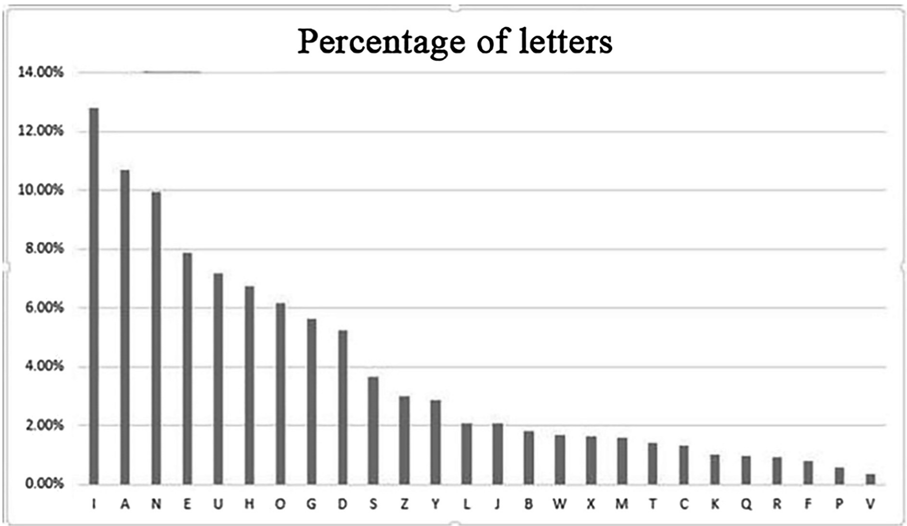

Fig. 2. Statistics of use frequency of pinyin letters [6]

1. The use frequency of vowels A, E, I, O and U which are generally used to form finals in pinyin is high, and one reason is that the final component is necessary for utilization of pinyin.

2. Apart from the vowels A, E, I, O and U, three consonants N, H and G also have a high use frequency. The reason is that N and G are the only two consonants that can form finals, and H can be combined with other letters to form initials.

3.2 Initials and Finals

Initials and finals are the most basic components of Pinyin. Pinyin contains 21 initials and 34 finals, as shown in the following table [7] (Tables 1 and 2).

Table 1. Table of initials

b玻	p坡	m摸	f佛	d得	t特	n讷
l勒	g哥	k科	h喝	j基	q欺	x希
zh(ẑ)知	ch(ĉ)吃	sh(ŝ) 诗	R日	z资	c此	s思

Table 2. Table of finals

	i |衣	u |乌	ü|迂
a啊	ia|呀	ua|蛙	
o喔		uo|窝	
e鹅	i.e.|耶		üe |约
ai哀		uai|歪	
ei诶		ui (uei) |威	
ɑo熬	iɑo|腰		
ou欧	iu(iou) |忧		
an安	iɑn|烟	uan|弯	üan|冤
en恩	in|因	un(uen) |温	ün|晕
ang昂	iang|央	uang|汪	
eng鞥	ing|英	ong(ueng) |翁	iong|雍

(Note: letter ü is substituted by Latin letter V in the existing input methods).

Considering that the input method layout uses the unit of single letters, this paper, by combining the forming rule of pinyin, divided the 26 letters into two types, named initials and finals respectively:

21 initials: B, P, M, F, D, T, N, L, G, K, J, Q, X, R, Y, W, Z, C, H and S

6 finals: A, E, I, O, U and V

3.3 Cacuminals and Velar Nasals

Cacuminals and velar nasals are common syllable combinations of pinyin, as shown in Table 3:

Cacuminals zh, ch and shi are formed by Z, C and S and H, respectively. These three cacuminals are also the only three initials formed by two letters.

Table 3. List of cacuminal and velar nasal combinations

Z, S, C, H	zh-,ch-,sh-
N, G	-ang,-eng,-ing,-iang,-iong,-ong,-uang

In nasal finals, the finals with –ng tails are velar nasals formed by finals N and G. The finals with –n tails are alveolar nasals.

In the letter combinations of pinyin, there are many combinations of two finals, such as ai and i.e. From the list of finals in Table 2, it can be seen that nasal finals are the only compound finals with initials. Velar nasals are the only nasals formed by combinations of initials, and use of initials must be combined with finals in other conditions. The extensive utilization of nasal finals in pinyin leads to the high use frequency of N and G.

3.4 Combinations of Initials and Final

Apart from initials Z, S, C, H, N and G which form cacuminals and velar nasals, there are 14 initials left. The list of combinations of these initials and the finals is as follows (Table 4):

In this paper, the 14 initials except Z, S, C, H, N and G were called independent initials. The following figures show the data statistics condition of combinations between these 14 independent initials and the finals. (Note: Dots in Figs. 4 and 5 are center points of the bar graph, and they reflect whether the combinations between the initials and AEI or between the initials and OUV have more combination possibilities.) (Fig. 3).

According to the above statistical data, the following rules can be obtained:

(1) The number of syllable combinations of letters F and W is relatively small, and there are also few syllable combinations between them and finals AEI and OUV. Generally, the number of syllable combinations of letters D and L are the most, and their combinations with finals AEI and OUV are also the most. Thus, we can consider putting F and W on the key relatively far from the finals but putting D and L on the key close to the finals.
(2) There are many syllable combinations between letters B, P and M and finals AEI, but fewer between letters B, P and M and finals OUV. There are few syllable combinations between letters K and R and finals AEI, but relatively more between letters K and R and finals OUV. Thus, we can consider putting B, M and P on the key relatively close to the finals AEI, but D and L on the key relatively close to the final OUV.
(3) The quantity of combinations of letters J, Q and X is basically the same, and their positions on the keys can be further analyzed by combining their use frequency.

Table 4. List of combinations of initials and the finals [8]

Initial	Combinations with AEI	Combinations with OUV	Total
J	-i,-ia,-i.e.,-ian,-iang,-iao,-iu,-iong,-in,-ing| 10 kinds	-u,-ue,-un,-uan|4kinds	14
Q	-i,-ia,-i.e.,-ian,-iang,-iao,-iu,-iong,-in,-ing | 10kinds	-u,-ue,-un,-uan|4kinds	14
X	-i,-ia,-i.e.,-ian,-iang,-iao,-iu,-iong,-in,-ing | 10kinds	-u,-ue,-un,-uan|4kinds	14
K	-e,-en,-eng,-a,-an,-ai,-ao,-ang |8kinds	-ong,-ou,-u,-ua,-uo,-un,-ui,-uai,-uan,-uang | 10kinds	18
T	-e,-eng,-a,-an,-ao,-ang,-i,-i.e.,-ian,-iao,-in,-ing |12kinds	-ou,-ong,-u,-uo,-un,-ui,-uan| 7kinds	19
P	-a,-ai,-an,-ao,-ang,-ei,-en,-eng,-i,-i.e.,-ian,-iao,-in,-ing | 14kinds	-o,-ou,-u|3kinds	17
Y	-a,-ao,-an,-ang,-i,-ian,-in,-ing |8kinds	-ou,-ong,-u,-ue,-un,-uan | 6kinds	14
L	-a,-ai,-ao,-an,-ang,-e,-ei,-en,-eng,-i,-i.e.,-ian,-iang,-iao,-iu,-in,-ing|17kinds	-ou,-ong,-u,-ue,-uo,-un,-uan,-v|8kinds	25
B	-a,-ai,-ao,-an,-ang,-ei,-en,-eng,-i.e.,-i,-ian,-iao,-in,-ing | 14kinds	-o,-u|2kinds	16
W	a,ai,an,ang,ei,en,weng |7kinds	o,u|2kinds	9
R	-ao,-an,-ang,-e,-en,-eng |6kinds	-i,-ou,-ong,-u,-uan,-ui,-un,-uo| 8kinds	14
M	-a,-ai,-ao,-an,-ang,-e,-ei,-en,-eng,-i.e.,-i,-iu,-ian,-iao,-in,-ing |16kinds	-o,-u,-ou | 3kinds	19
F	-a,-an,-ang,-ei,-en,-eng |6kinds	-o,-ou,-u | 3kinds	9
D	-a,-ai,-ao,-an,-ang,-e,-ei,-en,-eng,-i,-ian,-iao,-i.e.,-in,-ing,-iu|16kinds	-ou,-u,-uan,-un,-uo,-ui| 6kinds	22

(Note: dia and biang are hardly used in daily life and their use frequency in written texts is very small).

(4) Compared with the above initial letters, there is no obvious inclination between combinations of letters T and Y and the finals AEI or OUV. The positions of T and Y on the keys can be further analyzed by combining their use frequency.

In sum, this research divides pinyin letters into the initials and the finals, and summarizes the following rules: (1) Except V, the other 5 finals have a high use frequency. (2) The utilization of the initials includes 2 conditions: (1) independent utilization of the initials: generally, there are very few combinations between F and W and the finals, or between F and W and AEI and OUV, respectively; generally, the syllable combinations between D and L and the finals are the most, and the combinations between D and L and the finals AEI and OUV respectively are also the most; there are many syllable combinations between letters B, P and M and the finals AEI but few between letters B, P and M and the finals OUV; there are few syllable combinations between letters K and R and the finals AEI but relatively more between letters K

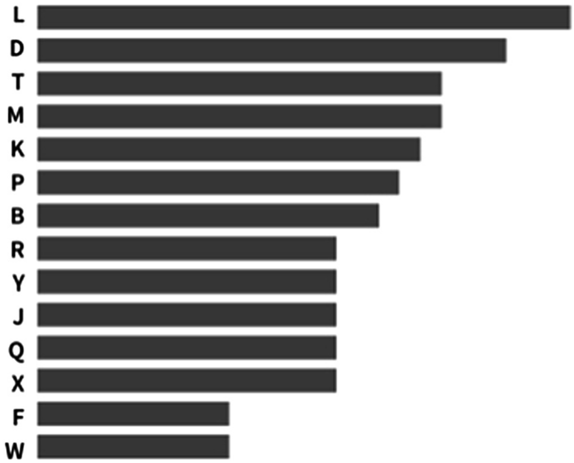

Fig. 3. Total quantity of possible combinations of syllables of the 14 independent initials in the descending order

Fig. 4. Quantity of combinations between the independent initials and AEI in the descending order

and R and the finals OUV; (2) combined utilization of the initials: since the initials H, N and G can be combined to form cacuminals zh-, ch- and sh- and velar nasals –ng, these three initials are very frequently used in pinyin.

Fig. 5. Quantity of combinations between the independent initials and OUV in the descending order

4 Design of 9-Key Keyboard Layout Based on Use Rule of Pinyin

4.1 Analysis of Existing 9-Key Keyboard

As shown in Fig. 6, keys of the existing 9-key keyboard are distributed in 3 rows and 3 lines, with the 26 Latin letters distributed on the 9 keys in the sequence of A, B, C, D, E, F, G, H, I, J, K, L, M, N, O, P, Q, R, S, T, V, U, W, X, Y and Z. There are 3–4 letters on each key. Generally one of the nine keys is reserved as a functional key which is used for symbol input, switching of the input methods and line feed, such as key 1 in Fig. 6.

1	2ABC	DEF3
4GHI	5JKL	MNO6
7PQRS	8TUV	WXYZ9

Fig. 6. Schematic diagram of layout of the existing 9-key keyboard

According to the positions of the keys and their relations with surrounding keys, this paper numbers the keys in sequence, including 1 center key (key 5), 4 side keys (keys 2, 4, 6 and 8) and 4 corner keys (keys 1, 3, 7 and 9). The center key is located at the center of the keyboard, adjacent to the 4 side keys and forming diagonal lines with the corner keys. The distance between the center key and all other keys is short. The side keys are located on four sides of the keyboard, adjacent to the center key and 2 corner keys and forming diagonal lines with 2 side keys. The distance between each side key and the 3 keys on the opposite sides is far. The corner keys are located at 4 corners of the keyboard, with each one adjacent to 2 side keys and forming diagonal lines with the center key. The distance between each corner key and the other 5 keys is far, as shown in Fig. 7.

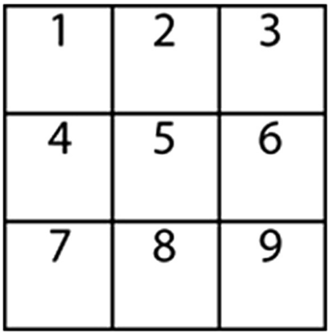

Fig. 7. Schematic diagram of keyboard number

4.2 Layout of Finals

The above analysis indicates that finals are a necessary part of pinyin combinations, and also the pinyin letters with the highest use frequency. Thus, the finals should be put on the keys that enable the finals to be combined with other letters on surrounding keys more conveniently. The distance between the center key and all others is short and the center key can be well coordinated with the surrounding keys. Besides, the existing researches show that key 5 has the best operation performance [9] in terms of the reaction time and the correction rate. Thus, in the new keyboard layout, the first step is to put the finals on the center key and one side key, as shown in Fig. 8.

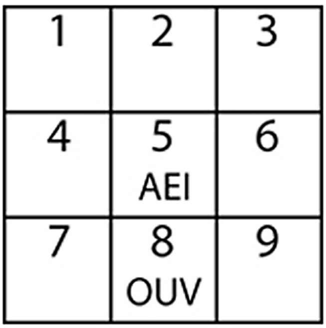

Fig. 8. Layout of keys AEI and OUV

The layout of concentrated distribution of finals on the center key and one side key has the following advantages:

(1) According with the use logic of pinyin and reducing the operation burden. The concentrated distribution of finals realizes clear division of the final zone and the initial zone in the keyboard. Users can input Chinese characters according to their logical thinking of inputting initials first and then finals. The explicit division of the initial zone and the final zone relieves the trouble of searching in the whole keyboard area when looking for letters, thereby significantly reducing the visual search and attention burden.
(2) Reducing the finger movement distance and improving the input efficiency. There are a lot of compound finals formed by combinations of the finals, such as “来lai” and “怪guai”. After adopting concentrated layout of the finals, the click operation which needs long-distance finger movement before changes to double click and click operation at adjacent keys. Therefore, the input operation becomes faster and more convenient and the finger movement distance of users is shortened, which helps improve the input efficiency.
(3) Making the application of the initial associating inputting method possible. After the finals are separated from the initials in the layout, the initial associating inputting method which can only be applied to the 26-key keyboard now can be used in the 9-key keyboard, thereby further improving the input efficiency.

Furthermore, the analysis of the letter use frequency indicates that compared with O, U and V, the use frequency of the finals A, E and I is higher. Therefore, this paper puts A, E and I at the center key and O, U and V at the side key adjacent to the center key, to form the keyboard layout containing the AEI key and the OUV key shown in Fig. 8 (The key where letters A, E and I are distributed is called the AEI key in this paper, et cetera).

4.3 Layout of Commonly-Used Initials

After the AEI key and the OUV key are determined as the above mentioned, the side keys having the closest linkage with the final zone are key 4 and key 6 which are adjacent to the AEI key and in diagonal relations with the OUV key. Thus, the initials with the high use frequency can be distributed at these two keys. Besides, since the number of letters on each key of the existing keyboard is generally 3–4. Four letters can be distributed on each of these two keys, and this can realize the maximal utilization of the convenience of these two keys.

The above analysis indicates that H, N, G, D and L are initials with a high use frequency and many combinations. Moreover, since letters Z, C and S are generally combined with H to form cacuminal initials, these three letters are also incorporated into initials and are distributed on the same key with H, which can facilitate input. Similarly, since letters N and G are generally combined to form the velar nasal final, these two letters are put on the same key to facilitate input. Thus, the other commonly used initials D and L can be put on the same key with N and G, i.e. H N G D L Z C S ==== ZCSH NGDL. The keyboard layout is shown as follows, in Fig. 9:

Fig. 9. Schematic diagram of layout of main initials

4.4 Layout of Other Initials

The other 12 letters and the blank key have to be distributed on the left 5 keys, including 1 side key and 4 corner keys. Among the 4 corner keys, 2 corner keys adjacent to the OUV key are closer to the final zone, so they can be combined with the finals more conveniently. The other 2 corner keys are relatively farther from the finals. Considering that a blank functional key is generally reserved in the 9-key keyboard and this key has a smaller use frequency compared with the letter keys, so that one corner key far from the final key can serve as the blank key. Thus, key 1 is temporarily set as the blank key.

Key 2 is the last side key. It is close to the AEI key but relatively far from the OUV key. Thus the initials with fewer combinations with OUV but more combinations with AEI are distributed on key 2. From the above analysis, it can be seen that there are more combinations between initials B, P and M and the finals AEI but fewer combinations between initials B, P and M and the finals OUV. Thus the letters B, P and M are distributed on key 2.

The corner key 3 is far from the final zone so that the letters with fewer combinations with the finals can be distributed on key 3. From the above analysis, it is known that the number of combinations between F and W and the finals is the smallest, and there are few combinations between F and W and the finals AEI and OUV. Thus, it is suitable to distribute F and W on key 3.

The 7 letters left are J, K, Q, R, T, X and Y. According to analysis of Figs. 4 and 5, there are fewer combinations between K and R and the finals AEI but more between K and R and the finals OUV; while there is no obvious inclination in the number of the combinations between J, Q, X, T and Y and the finals AEI or OUV. Thus, K and R can be temporarily distributed on the corner keys 7 and 9. The use frequency of letters shows that the use frequency of Q is relatively small, so it is temporarily distributed on the corner key 3. The final keyboard layout is shown in Fig. 10.

1	2 BPM	3 QWF
4 ZCSH	5 AEI	6 DLNG
7 JRX	8 OUV	9 TKY

Fig. 10. Layout of 9-key keyboard designed for Chinese input

4.5 Layout Adjustment

(1) **Adjustment according to use frequency of letters**

Considering that,

(1) P is the initial with the smallest use frequency, now it is put on the side key 2 close to all other keys.
(2) If operated with one hand, the corner key 3 is one of the most inconvenient keys in the keyboard. However, currently W on this key has a high use frequency, and “我(wo)” is used frequently in practical Chinese input. Thus, we should consider adjusting W to the position close to the letter O.
(3) The use frequency of Q on the corner key 3 is higher than that of P, so it can be adjusted.
(4) The corner keys 7 and 9 are convenient. While among the letters Y, J, X, T, K and R, the use frequency of R is small, so it can be adjusted.

Finally, W and R are exchanged, and P and Q are changed. The new layout is as follows (Fig. 11):

1	2 BQM	3 PRF
4 ZCSH	5 AEI	6 DLNG
7 JWX	8 OUV	9 TKY

Fig. 11. Keyboard layout after fine adjustment according to the use frequency

In addition, there are another 4 keyboard layout methods according to different positions of the OUV key. The ZSCH key and the DLNG key, the JWX key and the TKY key, and the blank key and the PRF key have similar convenience, so they can be exchanged.

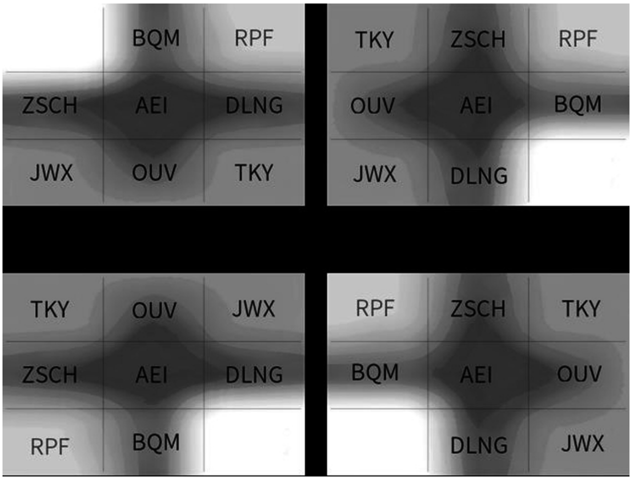

Fig. 12. Other equivalent layout schemes

Fig. 13. Schematic diagram of singe hand operation hot area

(2) Layout adjustment according to interactive hot area

When using mobile phones, 67% of user use right hands, and 49% of them hold mobile phones through one hand [10]. It is believed that if the keyboard layout is convenient and reasonable for single hand operation, there will be no problem for two hands operation. Thus, this research finely adjusts the keyboard layout based on the single hand operation in the interactive hot area. Figure 13 shows the schematic diagram of the thumb operation hot area when the operator holds the mobile phone with one hand.

The schematic diagram of the operation hot area is based on the 326 ppi 4.7-in iPhone 6 screen with 1334 * 750 pixel resolution. The dark area is the comfortable natural area, and the operation difficulty increases with shallowing of color. The light grey area is the area difficult to operate. Combining the key distribution of the keyboard, it can be seen that the line of keys on the rightmost of the keyboard and the side keys on the bottom of the keyboard are in the area relatively difficult to operate.

To improve the operation comfortableness and convenience of the keyboard, the keys which are less frequently used can be distributed in the light color area. In the keyboard layout scheme of this paper, the keys less frequently used include the blank key, the BQM key and the PRF key. Thus, the second layout mode in Fig. 12 is the optimum scheme.

In sum, the final keyboard layout scheme obtained is shown in Fig. 14:

1 TKY	2 DLNG	3 PRF
4 OUV	5 AEI	6 BQM
7 JWX	8 ZCSH	9

Fig. 14. The final keyboard layout scheme

5 Efficiency Verification

5.1 Explanation of Verification Method

The common method of keyboard comparison is to build an evaluation model, quantize the keyboard input operation and evaluate the operation efficiency of the keyboard with the appropriate evaluation function [11, 12]. Calculating the time needed to quickly move to a target based on the Fitts's Law and then conducting comparison and design is an important method of the human-computer interaction field [13, 14]. The common form is:

$$T = a + b\log_2(1 + D/W) \quad (1)$$

Where,

T—The average time for finishing movement Constants a and b reflect the inherent attribute of the equipment
D—The distance between the starting point and the target center
W—Target size

The Fitts's Law reflects that in a certain equipment condition, when the movement distance for operation is shorter, the operation time needed is shorter; when the target size is bigger, the operation time needed is shorter. This research builds the evaluation model of the 9-key keyboard on this basis.

5.2 Building of the Evaluation Model

In the Chinese input process of smartphones, the operator's input behavior can be summarized to be formed by two movements:

(1) Click the keys: for this operation, since there is no key process in the keyboard of the smartphone platform, the finger movement distance is very little in the click operation. Thus, time consumption of this movement is very short;
(2) Fingers move to the next key: the finger movement operation refers to the process that the finger leaves the current key and moves to the next key to be clicked. In this process, if the current key and the next key are the same one, the finger only needs to operate with double clicks. This omits the movement of the finger for a certain distance and simplifies the input process.

This section builds the analog test function based on the input operation actions, and tests the existing keyboard layout and the redesigned keyboard layout through the operational program. Furthermore, the input efficiency is verified by comparing the finger movement distance in the input process.

When comparing the typing time of these two kinds of keyboards, it is assumed that the length of the character string input by the user is n, the time for the finger to press on the key is T_0, the key reaction time is T_1, and the time for the finger to move from one letter to the adjacent one is T_{xy}($x < n-1$, $y < n$), then the time for inputting the character string

$$T = T_0 * n + T_1 * n + T_{12} + T_{23} + \ldots\ldots T_{(n-1)(n)}. \quad (2)$$

Assume that the finger movement speed is $V * W_{xy}$ (V is the average speed and W_{xy} is the weight of the influence of different finger operations on the speed) and the distance of adjacent two letters on the keyboard is S_{xy}($x < n-1$, $y < n$), then

$$T_{xy} = S_{xy}/\left(V * W_{xy} * \right) \quad (3)$$

The test of typing time is largely affected by the subjective conditions of the test objects, and measurement of T_0, V, T_1 and W_{xy} may be different for the test objects in different periods and with different equipments. Thus, to highlight the key points and simplify the test, it is assumed that the finger movement speed of the test objects at any time with any action is the constant, and in the condition of the same key reaction time of mobile phones, the test of typing time can be simplified to comparison of the finger movement distance $S = S_{12} + S_{23} + \ldots\ldots + S_{(n-1)(n)}$ during typing. Hence, the verification method of this research is simplified to comparison of the finger movement distance when typing with these two kinds of keyboards.

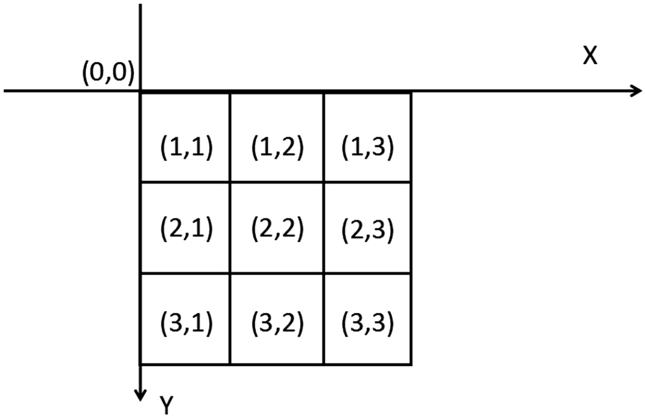

Fig. 15. The layout of the -key keyboard in the XY coordinate system

The layout of the 9-key keyboard is set in the XY coordinate system, and each key has its coordinate, as shown in the following figure. To simplify the complexity of distance calculation, each key of the 9-key keyboard is viewed as a square model (Fig. 15).

This paper writes the distance calculation program based on the above evaluation model. In the program, the coordinates of the 26 letters in the coordinate system are recorded according to the keyboard arrangement. When the user inputs the character string, the distance S_{xy} of two adjacent letters in the character string is calculated $S_{xy} = |(X_y, Y_y) - (X_x, Y_x)|$; the final distance S is calculated by adding all the S_{xy} and then is output. If S is smaller, it means the finger movement distance is shorter, i.e. the typing time is smaller; vice versa.

For example, to input a simple short sentence "我爱北京天安门wo ai bei jing tian an men", the operator presses 9-6-2-4-2-3-4-5-4-6-4-8-4-2-6-2-6-6-3-6 on the orignal keyboard in sequence; the total distance is $10 + 9\sqrt{2} + \sqrt{5}$, approximately 24.96. While on the redesigned keyboard, the operator presses 7-4-5-5-6-5-5-7-5-2-2-1-5-5-2-5-2-6-5-2 in sequence; the total distance is $11 + 4\sqrt{2}$, approximately 16.66.

The letter input path and the program calculation results are shown as follows (Fig. 16):

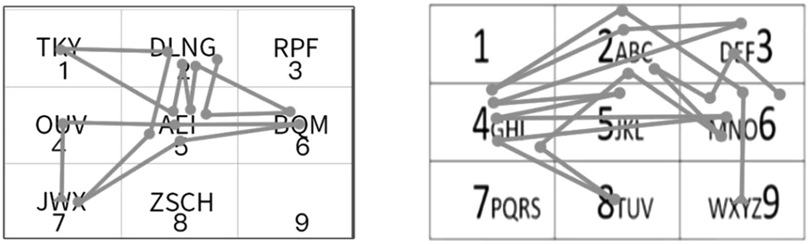

Fig. 16. Schematic diagram of the letter input path

Additionally, some other texts are tested, to compare the distance of these two kinds of keyboards. The results are shown as follows (Table 5):

Table 5. List of test results

Text source	Original keyboard	New keyboard	Optimization degree
Prose: Moonlight over the Lotus Pond (Number of words: 1,349)	5217.44	3408.36	34.67%
Xinhua net: How the Graphene industry breaks the ice and sets sail (Number of words: 1,785)	7072.67	4828.18	31.74%

According to the test result, the finger movement distance during Chinese input can be reduced by over 34% under the new keyboard layout. Therefore, compared with the existing keyboard, the new keyboard layout remarkably improves the Chinese input efficiency.

6 Conclusion

This research focuses on redesigning a Chinese input oriented 9-key keyboard layout scheme applied to the existing smartphone platforms according to the use rule of pinyin. Theoretically, the new layout mode can reduce 30%–40% finger movement distance of the operator, thereby improving the keyboard efficiency and realizing more efficient Chinese input. At the same time, the layout design provides possibility for the application of the initial associating inputting method and improves the efficiency of Chinese input through the small-screen electronic equipment.

With the development of the human-computer interaction technology, the keyboard design is bound to break through the existing mode, to provide more diversified selections for users with different demands. The keyboard design scheme of this paper can make full use of the advantages of the 9-key keyboard and create better human-computer interaction experience for Chinese input users and the elderly users.

The practical application of the keyboard layout scheme needs learning and adaptation of users. The transition process still needs further test, study and discussion.

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