An Adaptive Text Entry Method Based On Single-Key Minimal Scan Matrix for People with Severe Motor Disabilities

Saad Mohamed Lafi, Sidney Kan Boon Hock

Abstract— Virtual scanning keyboards (VSK) are used by people with severe motor disabilities as text entry and augmentative communication aids. These techniques applying virtual keyboard (VK) with scanning and access switch as alternative input method. The common Arabic VK layout is derived from the Arabic typewriter keyboard layout and not optimized for command entry speed and has several problems. This study was to design an alternative Arabic VSK (non-QWERTY key layout) and evaluate the performance and effectiveness of this innovative layout design for people with severe physical disability. The VSK layout was designed based on human-computer interactions (HCIs) and frequency-of-use for every user, employs the block-row-item and row-item scanning techniques. A repeated experiment was performed to compare the speed and accuracy of communication and text entry between the proposed method and the built in Windows 7 QWERTY virtual keyboard. Data analysis indicates that the proposed method provided better performance for the participant without increasing task difficulty. The performance enhancement of the proposed method is demonstrated in the paper with user testing results.

Index Terms— Virtual keyboards, assistive technology, augmentative communication aids, one-key scanning, scanning selection techniques.

1 Introduction

People suffering from motor disabilities such as cerebral palsy, quadriplegia, muscular dystrophy and the like, face difficulty in accessing computer-based systems since they cannot efficiently utilize standard computer access devices like mouse or keyboards. Consequently, Alternative computer access switches have been developed that require any active body of the user, including head, hand, mouth, foot, or eye can be used to operate such switches. Each of these switches is supported by virtual scanning keyboard (VSK). Scanning is the successive and periodic highlighting of virtual keyboard (VK) elements. When the highlighter reaches the wanted element, the user triggers an access switch to select the element [1].

For a user of a computer-based aid system, performance depends on both the VK layout and the scanning method. A major goal in the design and prescription of VSK is to reduce the motor requirements placed on the user [2], [3]. The main objective of this paper was to investigate the user performance with the common Arabic VSK layout and suggest improvements on that layout using some of the techniques to improve the entry efficiency of people with severe physical disability. These techniques depend on human-computer interactions (HCIs) and sustainability of the frequency-of-use for every user, employs block-row-item and row-item scanning techniques. Designing for diversity was a factor we considered carefully in this study [4]. We verified our claim that our methods enhance performance through user testing, which is also introduced in this paper.

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2 Virtual Scanning Keyboards (VSK)

Virtual keyboard is an accessibility utility refers to a software system displays a VK on the computer screen [5]. The standard computer keyboard is labelled with the QWERTY layout is applied to the most VKs interface. The keys are laid out spatially on the interface. Users make single letter selections from the interface to compose a text. To enable motor impaired users work with VKs, scanning and access switch based input methods are used. Figure 1 illustrates VSK in which a scanning is used to operate on common Arabic keyboard applied to the QWERTY layout. When the area containing the wanted character is scanned, the user selects it by triggering the access switch. An access switch is a specific intended hardware device that needs lesser motor control to function. Hence, the rate of scanning is important, since the user has to push and release the switch within the scanning delay for a highlighted region. Scan step delays in the studies range from 0.3 seconds to around five seconds [6].

Irrespective of the scanning delay, user performance depends on both the VK layout and the scanning method. The common Arabic keyboard layout is derived from the Arabic typewriter keyboards and applied to the QWERTY layout as shown in Figure 1. In the 1970s and 1980s, many computer organizations developed different forms for this layout including Microsoft Arabic Word, Apple MAC, AMEER, and Nafitha [7]. Nevertheless, no one of these keyboard standards was used by the computer industry, and the market adopted instead the currently used Arabic keyboard layout shown in Figure 1. This keyboard layout achieved broad acceptance in

PCs over other layouts when Microsoft adopted it for its Arabized products.

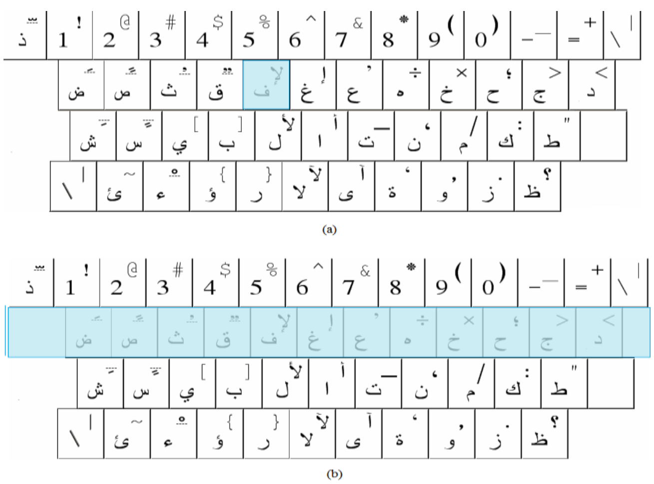

Fig. 1. Common Arabic VSK layout applied to the QWERTY layout. (a) Item scanning method. (b) Row-item scanning method.

However, for people with severe motor disabilities, the common Arabic keyboard layout is not optimized for performance and also has many obvious drawbacks. For example, the item scanning arrangement in Figure 1(a) is slow. It requires 19 scan steps to reach letter "ف". To address this, scanning keyboards normally operate some type of multilevel, or divide-and-conquer, scanning. Figure 1(b) displays row-column scanning. Scanning continues row to row. When the row including the wanted character is highlighted, it is selected. Scanning next enters the row and proceeds left to right within the row. When the wanted item is highlighted, it is chosen. Clearly, this is an enhancement. The letter "ف" for example, is selected in 7 scan steps in Figure 1(b): 2 row scans + 5 item scans. The row-item scanning of figure 1(b) is one of the several methods used to operate VKs. These different methods are debated in the following.

3 Scanning Techniques

Scanning is a technique used by individuals with severe physical impairments for entering text and other data into a computer based augmentative communication devices. It is an important method because it can be used with as little as one switch for input. A common implementation of scanning keyboards is to combine a VSK with a single key, button, or switch for input [1].

In single Switch-based scanning, the screen is assumed to represent a two-dimensional matrix of letters, numbers, symbols, words, or phrases. The items that are present on the screen are individual cells of the matrix which are sequentially highlighted, or scanned. Scanning is normally automatic, managed by a software timer, but manual scanning is also possible. In this case, the highlighted region is advanced as activated by the user action [8].

The most general form of matrix scanning is a three-level scan, often called the block–row–item scan [8]. In a block–row–item scan, the matrix items are grouped into blocks. Each block comprises of a set of rows of items. The system firstly begins a block level scan. During this process, the block that contains the desired item is selected by the user. When a block is selected, the system starts a row-level scan inside the block. During the row level scanning, the row in which the desired item lies is selected. And then the items of the selected row are scanned. Once the scanning reaches the wanted item, the item is selected. A variation of block–row–item scan is the diagonal selection mode. In this technique, a block is split into two triangular matrices based on the main diagonal. In the first stage of the scanning, the two parts of the matrix are periodically highlighted, and the user selects the triangle where the target item is located. Then a row scanning is applied for its rows and so on. Other two variants of the block–row–item scanning are the row–item scanning and the item scanning explained earlier.

Scanning and access switch based access methods are generally much slower than mouse/keyboard based access methods. To enhance performance, many alternate scanning mechanisms along with many techniques to improve performance in scanning based interactions have been developed. In this paper, we reviewed these alternate scanning mechanisms and various performance improvement techniques. However, the performance improvement techniques suffer from some serious limitations. These limitations along with our solutions to overcome them are discussed next.

4 Proposed Improvements

To improve performance of a scanning based interaction, several methods have been studied. These methods include the use of different letter arrangements, word or phrase prediction, and adjusting the scanning interval. The most obvious improvement for row-item scanning is to dynamically rearrange letters by placing frequent letters close to the beginning of the scan sequence, such as in the initial row or in the first arrangement in a column [9], [10], [11], [12]. However, studies like [13] rejected this dynamic rearrangement scheme, claiming that the constantly changing display would require an excessive degree of concentration by the user. The need to search the dynamic matrix after each character may imply that the scanning delays and switch closure times must increase to maintain a constant accuracy, thereby offsetting the decrease in switch counts and yielding small or negative time savings [14]. Moreover, users suffering from visual impairments have trouble getting used to the quick dynamic rearrangement of the keys. They like the static scan instead.

Resent researches on performance improvement of VSK concentrates on matrix scanning using a three-level or higher selection scheme, known as quadrant scanning [15], [16], [17] and [18]. The main idea is to scan through a group of items. The initial selection enters a group. Scanning then continues among smaller groups within the selected group. The second choice enters one of the smaller groups, and the third choice selects an item within that group. There is a trade-off among the number of levels to travel across and the number of items to pass over in each level. Group scanning is most applicable to allow access to a large number of items [15], [19].

Apart from such augmentation, the goal is usually to reduce the total number of scan steps to reach the desired character. In this paper, the focus mainly on the concept of the rearrangement and quadrant scanning mechanisms, because only requires one user input selection. In the proposed method to overcoming the limitations of the previous methods and to improve user performance, rather than dynamically rearranging the items after each character selection, fixed character layouts are chosen. However, During the initial assessment of each user the default interface layout arranged based on most frequency in Arabic language, which each letter has high frequent of use takes place has low scanning steps as shown in Figure 2.

(a)

(b)

Fig. 2. (a) Numbers represent scan steps to reach this key.
(b) Default auto-scanning VSK layout design.

The interface captures each user action and records them in a user profile. This record file is used to identify the actual events (*such as the most frequently used characters and most frequently used words for the user)*, and an event identification number is attached with each event. Based on the pattern of events the task history of usage is determined and prediction is provided in accordance with the particular user's model and task history. The user profile personalization is updated remains indifferent towards a user for his distinctive interaction patterns at a different context and time. When the user exits the system the fine-tuned form of the interface and the user records are stored for modification of the existing knowledge base. Based on this knowledge, when the user logs into the system again, the system will provide the user an appropriate interface and all new configuration changes made by the user will be automatically saved for later use and so on.

In the proposed framework, the user profile is used to predict a proper VSK layout from the knowledge captured for that user. In that predicted interface, the interface components will be customized according to each individual user. So user will get a taste of personalization before starting interaction. The speed and accuracy of the scanning mechanism are increased with the help of arranging of the items based on the user profile captured, and the scanning mechanism selected.

5 Experiments and Performance Evaluation

The study was conducted using 20 subjects with no cognitive impairments and who are native speakers of Arabic language. During selection of subjects, main emphasis was given on getting as much diversity as possible, the variety of the selected subjects according to age, computer proficiency, and education background. After getting training around 15 users used our system. Finally, we could identify twenty sessions of using the system. These twenty sessions were examined. The main focus was on measuring the performance of the proposed method. A number of well-known measures have been used including scan steps saving, text-entry rate, communication rate (CR) and accuracy of text entry (error rate). The usability evaluation and analyses were carried to compare the performance with that of the QWERTY VSK built in Microsoft Windows 7. The performance measuring technique is illustrated in the next section and the analysis results for each type of layout is explained and clarified.

5.1 Scan steps per character (SSPC)

Scan steps per character (SSPC) is proposed here as a characteristic measure for scanning VKs. SSPC is the number of scan steps, on average, to enter a character of text using a given scanning keyboard in a given language. The average of SSPC is calculated as follows:

$$SSPC = \frac{\sum totalScanSteps(S)}{\sum_{S \in corpus} totalNumberSentences(N)} \quad (1)$$

Where, *totalScanSteps(S)* is the total of scan steps sequence needed to type a message *S,* and *totalNumSentences(N)* is the total number of sentences in the corpus (in letters) .

5.2 Text entry speed

An advantage of SSPC is that, it directly produces text entry speed, T_{entry}, in words per minute (WPM), assumed a scanning delay SD in milliseconds then:

$$T_{entry} = \left(\frac{1}{SSPC}\right) \times \left(\frac{1000}{SD}\right) \times \left(\frac{60}{5}\right) \quad (2)$$

Where, the first term *1/SSPC* changes *SSPC* into characters per scan step. Multiplying by the second term 1000/500 produces characters per second and by the third term yields WPM. For instance, if the *SD* is, say 500 MS, and *SSPC* = 4.44 *sspc*, then,

$$T_{entry} = \left(\frac{1}{4.44}\right) \times \left(\frac{1000}{500}\right) \times \left(\frac{60}{5}\right) = 5.4wpm \quad (3)$$

Generally, WPM is mostly calculated to report the speed of a text entry method in similar researches. The common definition for "word" is a term of 5 characters, including space [20]. However, in our case, it's not reliable if we concentrate on WPM as the total of characters per word of syllabic script and that of alphabetic language might not be the same. We hesitate to measure 5 characters per Arabic word as there is no exact source. Therefore, we based on characters per minute (CPM) to evaluate the performance of the proposed method. Herein, we calculate CPM by dividing the written text which contains of 135 characters (in the experiments) with the completion SSPC of each experiment.

We have three groups of subjects — first group refers to the subject that experiences proposed method with row-item scanning (5 users). Second group is the subject that has experience proposed method with block-row-item scanning (5 users). The third group consists of 5 subjects who have basic knowledge of QWERTY layout of block scanning built in Microsoft Windows 7 method. Subjects were presented with 20 target sentences. The same set of 135 letters was used in each trial, but the order was randomized.

Figure 3 depicts SSPC of these three groups. For initial group at the first session, scan steps was 4.44 SSPC. The second group subject started with 5.66 SSPC. In both groups, the scan steps of this method gradually decrease while the subject continues using the same log file. This decline continues until it reaches a point where all the characters frequent and likely to appear in the text arranged in the places near the beginning of the scan sequence. The third group subject started with 8.11 SSPC with the QWERTY VSK built in Microsoft Windows 7. And it is constant in all sessions.

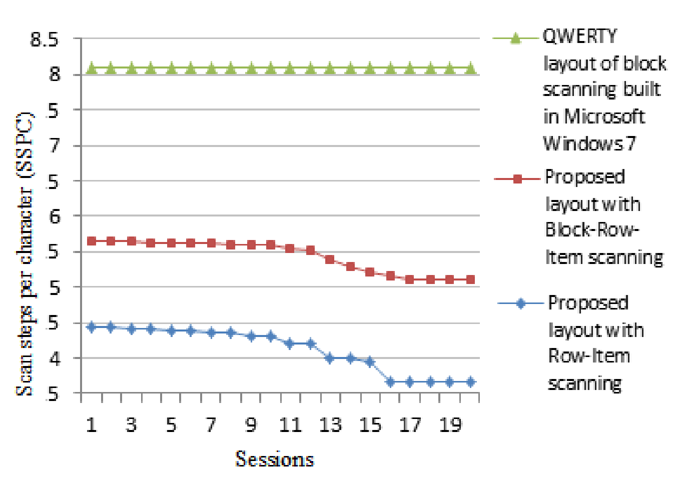

Fig. 3. Variation of SSPC for the 3 subjects using proposed method and the QWERTY layout of block scanning built in Microsoft Windows 7.

As the figure 3 shows, SSPC of the proposed methods is lesser in each trial in comparison to that of the existent one. We observe that the graph of the first group subject and that of the second group subject yield similar trend that SSPC of the proposed method is lower than that of the existing method. This is telling us that our method yield better speed since the subjects that have the same experience of both methods could go faster with our proposed method even at the first time.

5.3 Measuring accuracy and usability

A In addition to the previous measuring techniques' accuracy and usability often used as performance measures for evaluating input systems too. Both were evaluated by experiments under the condition of proposed methods and compared to the performance of the scanning VSK with that of the QWERTY layout built in Microsoft Windows 7.

The experiment utilized a single group repeated measurement with a counterbalance design. We obtained twenty measurements of word entry speed. The means of the factors SSPC and WPM were averaged across all sessions and participants for the three input methods. Table 1 lists the average SSPC, CR and error rate for all input methods. As shown in table, the results demonstrated that the SSPC of using proposed methods was lower than using the Windows 7 VSK, the CR was higher and no significant difference between the error rates on proposed and existing one.

TABLE 1
AVERAGE OF SSPC, CR AND ERROR RATE FOR DIFFERENT TYPES OF LAYOUTS.

Layout type	Average SSPC with 750 MSEC scan delay	Average CR with 750 MSEC scan delay	Error rate
Proposed layout with Row-Item scanning	3.66 SSPC	4.41 WPM	0.838
Proposed layout with Block-Row-Item scanning	5.12 SSPC	3.13 WPM	0.852
QWERTY layout of block scanning	8.11 SSPC	2.97 WPM	0.863

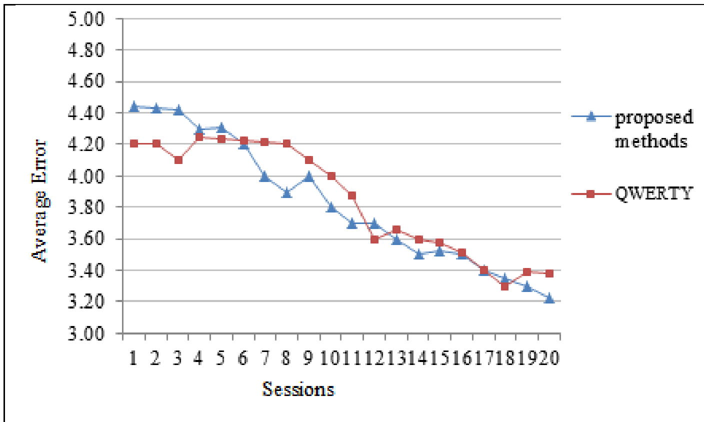

Fig. 4. Average error rates by variant and session.

And as shown in figure 4, the result reveals that the participant performed better while using proposed input methods than the using Windows 7 VSK. Moreover, we observed that, as the user continues using the system (i.e. for longer usage), the ratio of the number of inputs to number of words decreases. So that effort from users' side will not decrease remarkably with long usage of the system.

6 Conclusion

Single-key VSKs is a very slow method used by individuals with severe disabilities for entering text and other data into computers and augmentative communication devices. This paper has introduced improvements to the layout of Arabic VSK. The designed VSK layout depends on HCIs and frequency-of-use for every user, utilizes block-row-item and row-item scanning techniques. The improvements based initially on the most frequency in Arabic language and then the user profile. This file captures each user action (*such as the most frequently used characters and most frequently used words for the user*). The user profile is used to predict a proper VSK layout from the knowledge captured for that user. In that predicted VSK, the interface components will be customized according to each individual user. So user will get a taste of personalization before starting interaction. The speed and accuracy of the scanning mechanism are increased with the help of rearranging of the matrix items depends on the knowledge captured, and the scanning mechanism selected.

We have presented three aspects of the evaluation of the present work performed i.e. a user evaluation of the performance, efficiency and usability of the system. The design of the metrics and methods used to evaluate the proposed method is influenced by the work of [21], [22], and [23]. In a user study to determine the practical speed improvements, users achieved an average mean text entry speed of 3.13 to 4.41 wpm. This represents advanced increase over QWERTY layout. The evaluation shows that, the proposed method worked more effectively and provides much more flexibility in terms of versatility layouts and features than existing one. Future study that validates the effectiveness of other aspects for people with motor disabilities is needed. Speed of entry is not the only measure for an effective input system. We should take into account other problems such as simple learning, low error rates, and ease of error correction. The time consumed on correcting typing errors has a main influence on text entry efficiency.

References

[1] C. E. Steriadis and P. Constantinou, "Designing human-computer interface for quadriplegic people," ACM Trans. Computer-Human Interaction, vol. 10, pp. 87-118, 2003.

[2] R. D. Beukelman and P. Mirenda, Augmentative and Alternative Communication, 2nd ed. Baltimore, MD: Brookes, 1998.

[3] H. S. Venkatagiri, "Efficient keyboard layouts for sequential access in augmentative and alternative communication," Augmentative Alternative Commun., vol. 15, pp. 126–134, 1999.

[4] Lopes, J. B.: Designing user interfaces for severely handicapped persons", Workshop on Universal Accessibility of Ubiquitous Computing, (2001) 100-106.

[5] I.S. MacKenzie, S. X. Zhang, and R. W. Soukoreff, "Test entry using softkeyboards," Behaviour & information technology, vol. 18, no. 4, 235- 244, 1999.

[6] MIR ´O, J. AND BERNABEU, P. A. 2008. Text entry system based on a minimal scan matrix for severely physically handicapped people. In Proceedings of the 11th Conference on Computers Helping People with Special Needs (ICCHP'08). Springer, Berlin, 1216–1219.

[7] Jordan Institution for Standards and Metrology (JISM). 1994. Minutes of Meeting of the Arabic Letter Committee. Mar 10, 1994, Amman, Jordan.

[8] FELZER, T., NORDMANN, R., AND RINDERKNECHT, S. 2009. Scanning-based human-computer interaction using intentional muscle contractions. Universal Access in Human-Computer Interaction Part II, (HCII'09). Springer, 309–318.

[9] DAMPER, R. I. 1984. Text composition by the physically disabled: A rate prediction model for scanning input. Appl. Ergon. 15, 289–296.

[10] JONES, P. E. 1998. Virtual keyboard with scanning and augmented by prediction. In Proceedings of the 2nd European Conference on Disability, Virtual Reality and Associated Technologies. University of Reading, UK, 45–51.

[11] Baletsa, G., Foulds, R., & Crochetiere, W. (1976). Design parameters of an intelligent communication device. In Proceedings of the 29th Annual Conference on Engineering in Medicine and Biology, p. 371. Chevy Chase, MD: Alliance for Engineering in Medicine and Biology.

[12] BALJKO, M. AND TAM, A. 2006. Indirect text entry using one or two keys. In Proceedings of the ACM SIGACCESS Conference on Computers and Accessibility (ASSETS'06). ACM, New York, 18–25.

[13] LIN, Y.-L., WU, T.-F., CHEN, M.-C., YEH, Y.-M., AND WANG, H.-P. 2008. Designing a scanning onscreen keyboard for people with severe motor disabilities. In Proceedings of the 11th Conference on Computers Helping People With Special Needs (ICCHP'08). Springer, Berlin, 1184–1187.

[14] Demasco, P. (1994). Human factors considerations in the design of language interfaces in AAC. Assistive Technology, 6, 10-25.

[15] Bhattacharya, S., Basu, A., & Samanta, A. (2008). Performance Models for Automatic Evaluation of Virtual Scanning Keyboards. IEEE Transactions on Neural Systems and Rehabilitation Engineering, 16(5), 510-519.

[16] A. Mukherjee, S. Bhattacharya, P. Halder, and A. Basu, "A virtual predictive keyboard as a learning aid for people with neuro-motor disorders," in *Proc. 5th IEEE Int. Conf. Adv. Learn. Technol. (ICALT)*, 2005, pp. 1032–1036.

[17] FELZER, T., NORDMANN, R., AND RINDERKNECHT, S. 2009. Scanning-based human-computer interaction using intentional muscle contractions. *Universal Access in Human-Computer Interaction* Part II, *(HCII'09)*. Springer, 309–318.

[18] LIN, Y.-L., WU, T.-F., CHEN, M.-C., YEH, Y.-M., AND WANG, H.-P. 2008. Designing a scanning onscreen keyboard for people with severe motor disabilities. In *Proceedings of the 11th Conference on Computers Helping People With Special Needs (ICCHP'08)*. Springer, Berlin, 1184–1187.

[19] SIMPSON, R. C. AND KOESTER, H. H. 1999. Adaptive one-switch row-column scanning. *IEEE Trans. Rehab. Engin. 7*, 464–473.

[20] Yamada, H. (1980). A historical study of typewriters and typing methods: From the position of planning Japanese parallels. 2, 175-202.

[21] Yun, L. L., Ming, C. C., Ya, P. W., Yao, M. Y., & Hwa, P. W. (2007). A Flexible On-Screen Keyboard: Dynamically Adapting for Individuals' Needs. *Universal Access in Human-Computer Interaction. Applications and Services, 4th International Conference on Universal Access in Human-Computer Interaction, UAHCI 2007 Held as Part of HCI International 2007 Beijing, China*, (pp. 371-379).

[22] Yun, L. L., Ting, F. W., Ming, C. C., Yao, M. Y., & Hwa, P. W. (2008). designing a scanning on-screen keyboard for people with severe motor disabilities. *Computers Helping People with Special Needs, 11th International Conference, ICCHP 2008* (pp. 1184-1187). Springer-Verlag Berlin, Heidelberg .

[23] Ouk, P., Ye Kyaw, T., Matsumoto, M., & Urano, Y. (2008). The design of Khmer word-based predictive non-QWERTY soft keyboard for stylus-based devices. *Proceeding VLHCC '08 Proceedings of the 2008 IEEE Symposium on Visual Languages and Human-Centric Computing*, 225-232.