Reducing Scanning Keyboard Input Errors with Extended Start Dwell-Time

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Abstract. Some individuals with reduced motor function rely on scanning keyboards to operate computers. A problem observed with scanning keyboards is that errors typically occur during the first group or first cell of a group. This paper proposes to reduce such errors by introducing longer dwell-times for the first element in scan sequences. The paper theoretically explores several designs and evaluates their effect on overall text entry performance.

Keywords: scanning keyboards, motor disability, dwell-time

1 Introduction

Conventional usage of computers usually comprises users' actions of typing and clicking. To perform such task in a satisfactory and efficient way, a certain level of motor control provided by sensory-motor integration is needed. Individuals with high levels of movement impairment have limited access to the independent and efficient use of a computer. In a study with individuals with quadriplegia due to spinal cord injury (spine levels of C5 to C7), it was found that high levels of motor impairment limit the independence and efficiency in computer usage not only in typing tasks, but also in the operation of mouse, cables, and accessories [1]. The current study focuses on text entry.

Individuals with motor disabilities may be unable to enter text using conventional keyboards. One common aid is scanning input [2], which allows the user to input text and control computer with just a single switch. The principle of scanning keyboards is that the characters are displayed in a regular grid. These elements are then highlighted in turn for a time interval known as the dwell-time; when an element is highlighted, it can be selected by the user by using the switch. One practical scanning pattern is to first scan through the row, followed by scanning through the cells of a selected row. With such a configuration, the user selects a character in two steps.

One problem that has been observed in the literature is that users typically make more mistakes with the first element of a scan, being it the first row or the first cell of a row [3].

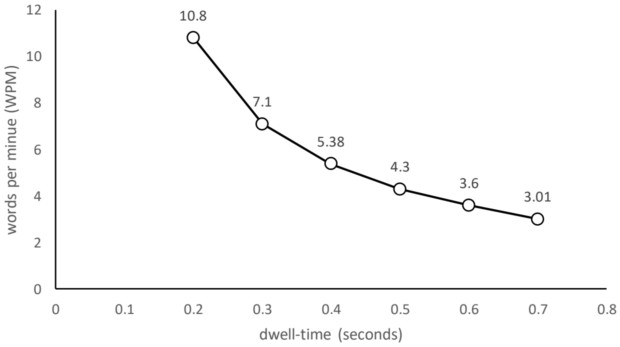


Fig. 1. Productivity in terms of words per minute as a function of uniform dwell-time with a QWERTY scanning keyboard.

One possible explanation for this could be that the elements usually are scanned with the same dwell-time for each element; since the dwell-time is the bottleneck in scanning keyboards, one usually tries to keep the dwell time as small as possible. However, research into text input rhythmic patterns has found that text is often inputted according to some rhythmic pattern [4], and that there typically is a longer delay between characters than for the steps within characters [5]. One possible cause is that users may need a small mental break- or pause between consecutive characters. However, the scan keyboard paradigm is different to non-scanning methods in that the system drives the text entry, not the user. As soon as a character is input, the new character input starts immediately without pause.

This theoretical study proposes to introduce a longer dwell-time for the first element of a scan sequence. Based on empirical results from the literature, this study models the effect of introducing such a delay on both error rates and text entry performance.

2 Background

The design of universally accessible technologies [6] such as self-service kiosks in public spaces [7, 8, 9] and smart home technologies [10] focus on general characteristics of colour contrast [11, 12, 13] and text readability [14, 15, 16]. Such efforts also include the design of assistive technologies for specific groups. Broadly speaking, assistive technologies can be divided into those that address sensory disabilities including low vision [17, 18, 19], blindness [20, 21, 22], mental disabilities [23] such as dyslexia [24, 25, 26], and motor disabilities [27, 28]. One iconic assistive technology for mobility impairments is the wheelchair. Wheelchair mobility research typically focuses on manual wheelchair design [29, 30], handrim-activated power assisted wheelchair design [31, 32], wheelchair configuration [33], handrim design [34, 35], hand pressure [36], and manoeuvrability [37].

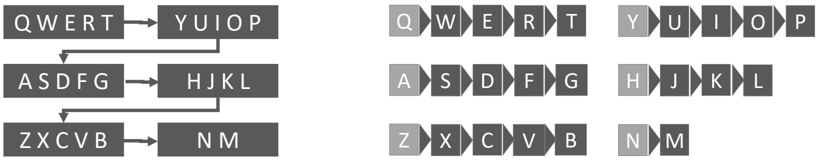


Fig. 2. Scanning keyboard: group sequence (left), cell sequence (right).

There are several approaches for assisting individuals with reduced motor function to input text on computers such as chording [38, 39, 40], tapping [41, 42], menu driven text entry [43], ambiguous keyboards [44], text prediction [45], adjusting the keyboard layout [46], and scanning keyboards [47, 48, 49]. One advantage of scanning keyboards is that they support recognition rather than recall [50, 51].

Scanning keyboards are slow compared to other types of text entry techniques and most of the research attention has thus focused on optimizing the virtual keyboard layout [52, 53, 54]. Errors then become even more costly and critical. Several studies have addressed issues involving errors [50, 55]. It has been found that specific keyboard based error-correcting mechanisms such as reverse-scanning-direction buttons and abort buttons are not effective [55].

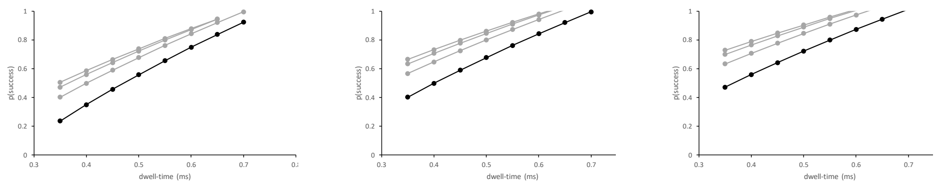
One challenge with scanning input research is to obtain disabled participants and having too short experimental sessions [55, 56]. Consequently, researchers have proposed theoretic models [3, 56, 57]. This study exploits the scan steps per character measure introduced by MacKenzie [57] and a model for errors based on empirical data proposed by Francis [3].

3 Method

Francis [3] proposed a model for the probability of making a correct decision for a given location on a virtual keyboard. This model was based on empirical data from a between-subjects experiment with 3 × 60 students which had to select numbers on a 8 × 8 grid of numbers with dwell-times of 200, 350, and 500 milliseconds. Slightly longer dwell-times were used in a study of a four-key ambiguous keyboard [44] ranging from 700 to 1100 milliseconds. The results were analysed using a genetic programming algorithm, which yielded the following expression:

$$p(correct) = a + b\left[\sqrt{R} + \sqrt{C} + \frac{9(10)^{1/4}}{\sqrt{D+(RC/3)^{1/4}}}\right]^{1/4} \tag{1}$$

where R and C are the row and column numbers, D is the dwell time and a and b are constants with the values of 23.43 and -11.40, respectively. In simple terms, Francis observed that error rates were higher for all the elements along the first row and the first column compared to the other cells in the matrix. One explanation for this is that users get too little time to make the selection when the cursor is first displayed on the left side.



Row = 1, cell = {1, 2, 3, 4} Row = 2, cell = {1, 2, 3, 4} Row = 3, cell = {1, 2, 3, 4}

Fig. 3. Probability of success as a function of dwell-time for the first four elements at column 1, 2 and 3 respectively.

Since the first row is missed in a similar manner, all the cells in this row are missed. This study refers to Eq. (1) as *P*(*C*, *R*, *D*) since the probability of success can be considered a function of *C*, *R*, and *D*.

Clearly, the scanning input bottleneck is the dwell-time since the total time to input a character is the sum of all the dwell-times for all the individual scan steps. One useful measure is the scan-steps-per-character (SPC) [22]

$$SPC = \sum_i f_i s_i \tag{2}$$

where *f* is the frequency of character *i*, and *s* is the number of scanning steps to reach character *i*. This measure assumes uniform dwell-times. This phenomenon is illustrated in Fig. 1, which shows how the text entry speed in terms of word per minute changes as function of dwell-time. A rough estimate of a lower bound for the words-per-minute was estimated using

$$WPM = \frac{60}{5D \times SPC} \tag{3}$$

Clearly, shorter dwell-times give faster text entry speeds, while the decrease in text entry speed becomes less prominent with larger delays.

The analysis in this study is based on a QWERTY scanning keyboard due to users' familiarity with QWERTY [58]. The scanning keyboard comprises six groups, namely QWERT, YUIOP, ASDFG, HJKL, ZXCVB, and NM. The two-step left-to-right scanning procedure [59] is illustrated in Fig. 2. Although the analysis is based on this QWERTY design, the general patterns will apply similarly to other layouts.

This study assumes that the probability of success can be increased by making the dwell-times of the first elements longer. Using Francis' model [3] in Eq. (1), the probabilities of success were plotted as a function of dwell-times for the first element in the first group (QWERT) or *P*(1, *R*, *D*), second group (YUIOP) or *P*(2, *R*, *D*) and third group (ASDFG) or *P*(3, *R*, *D*), respectively (see Fig. 3). All the plots show that the probability of success associated with the first cell in the group (black) is lower than the success probabilities for the remaining cells (grey). Moreover, Fig. 3 shows that the success probabilities for the first groups are lower than the probabilities for subsequent groups.

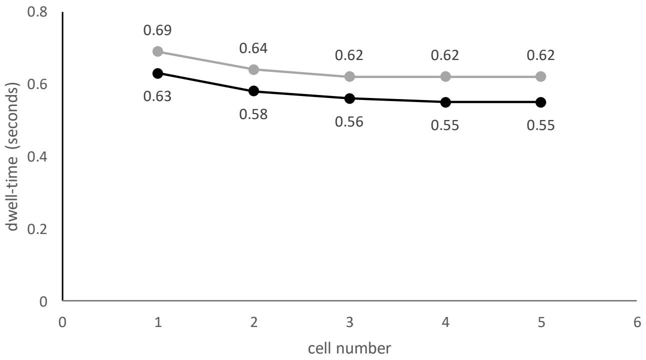


Fig. 4. Dwell-time as a function of cell number with success probabilities of 0.8 (black) and 0.9 (grey), respectively.

By using Francis' model [3] in Eq. (1) the dwell-times needed to achieve probabilities of success at levels of 0.8 and 0.9 are estimated and shown in Fig. 4, namely

$$D = Q(P, R) \tag{4}$$

where D is the dwell-time given by the function Q of the probability level P and cell number R. To achieve a success probability of 0.9, the first element needs a dwell time of 0.7 seconds, the second element needs a dwell time of about 0.65 seconds and the remaining elements need dwell times of just over 0.6 seconds.

Note that these predictions are based on a mathematical model that is a best-fit of the empirical data. One may make a simplification where only the first element is associated with a longer dwell-time and the remaining elements are assigned a shorter dwell-time, based on the theory of mental break between consecutive characters. With such simplifications, at what levels should the first and the subsequent dwell-times be set to achieve a text entry speed? Using Eq. (2) and Eq. (3) we can redefine SPC in terms of two dwell times D_1 and D_2:

$$SPC = \sum_{i \in C_1} f_i s_i + \sum_{j \in C_2} f_j s_j \tag{5}$$

where C_1 and C_2 are the set of characters with dwell times of D_1 and D_2, respectively. The two sums can be considered constant since they are independent of the dwell time.

$$SPC = K_1 + K_2 \tag{6}$$

If we substitute this into the equation for WPM, we get

$$WPM = \frac{60}{5(D_1 K_1 + D_2 K_2)} \tag{7}$$

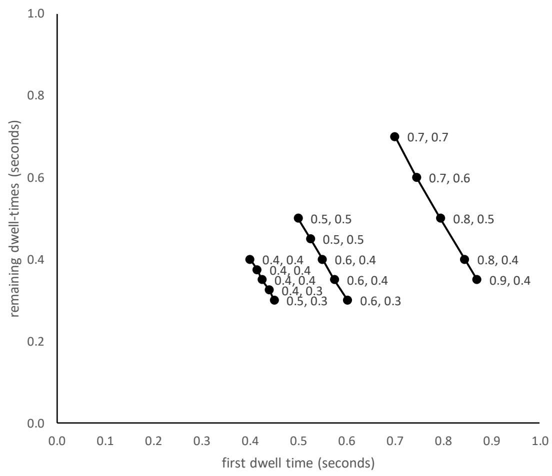


Fig. 5. The trade-off between the length of the dwell-time for the first cell and remaining cells for different speeds (3.01, 4.3, and 5.3 words per minute).

Solving for D_1 we get

$$D_1 = \frac{60}{5 \times WPM \times K_1} - \frac{K_2}{K_1} D_2 \tag{8}$$

By simplifying the expression in terms of constants, it is apparent that there is a linear relationship

$$D_1 = \frac{1}{WPM} c_1 - c_2 D_2 \tag{9}$$

Clearly, the relationship between D_1 and D_2 is independent of the *WPM* and is linear with a negative slope. The slope is the ratio of the SPCs for the two-character groups. Moreover, the range is inversely proportional to the *WPM*.

Fig. 5 shows the function of dwell-time of the first cell plotted against the dwell-times for the remaining cells along a scan for 3.01, 4.3, and 5.3 words per minute, respectively. As seen, the higher text entry speeds, the shorter the dwell times. Moreover, the shorter the dwell times, the shorter the range of variability.

Fig. 4 shows that for the QWERTY layout, there is an approximate 2:1 relationship between the dwell-time of the first cell versus remaining cells. That is, to increase the dwell time of the first cell, the dwell time of each of the remaining cells are halved similarly. Sincethere must be a lower bound on the dwell-time for the remaining cells, say 0.3 seconds, there is also an upper bound on the maximum dwell-time for the first cell.

4 Conclusions

This study explored the effects of extending the dwell-time for the first elements in a sequence during scanning keyboard text entry. By extending the dwell-time on the first element, it is assumed that the probability of successful decision for these first elements increases, as the user is given more time to get ready for inputting the new character. The model shows that it is possible to increase the dwell-time of the first element without sacrificing performance if the remaining dwell-times are reduced. For the QWERTY design explored, the increase in dwell-time of the first element must therefore be compensated by a half reduction in dwell-time for each of the remaining elements. As with most theoretical studies [60, 61, 62, 63], the theoretical results herein must be confirmed with observations of actual users.

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