On-line Adjustment of Dwell Time for Target Selection by Gaze

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ABSTRACT

In eye typing systems, a dwell time that adjusts to the user's natural typing speed is highly desirable. We present an algorithm for on-line adjustment of dwell time developed after detailed analysis of exit time upon selection of virtual keys. Exit time was measured using a wide range of dwell times for key selection (300-1100 ms). The results suggest that there was considerable variability in exit time among users indicating the need for calibration of the algorithm. The algorithm was evaluated in a user study and proved to be efficient. We also discuss the shortcomings of the current algorithm's implementation.

Keywords

Eye movements, eye tracking, text entry, virtual keyboards

ACM Classification Keywords

H5.2. Information interfaces and presentation (e.g., HCI): User interfaces – input devices and strategies, interaction styles

INTRODUCTION

Eye-based text input is one of the areas in alternative communication media that attracts major research interest. Among the techniques used to emulate keystrokes on virtual keyboards, selection by dwell time is employed most frequently in recent systems.

Dwell time is an uninterrupted period of time the gaze is required to stay on a key for that key to be selected. As noted by many, choosing a particular value for dwell time is quite important [1, 2, 5, 6]. On many occasions, a compromise has to be reached: having a relatively short dwell time is desirable for the system to be highly responsive, yet the dwell time cannot be made too short to avoid the Midas touch problem (when an object is selected unintentionally during regular scan of the screen contents) [2].

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As a rule, dwell time settings for conventional eye-typing systems are fixed values that range from 400-1000 milliseconds [5, 6]. To optimize performance, some of the systems allow the users to adjust the dwell time value as they wish. Among other things, this allows to reflect changes in the typing skills of the user over extended periods of work with the system. Since novice users are unfamiliar with the on-screen keyboard layout, some time is usually required for them to locate the character they need. Meanwhile, experienced users are already familiar with the layout, so they spend much less time on searching the required character. Users with different skills would thus need different dwell time settings for comfortable interaction.

Recently, an idea was put forward that dwell time should automatically adapt to the user's natural typing speed for user satisfaction and increased performance [1]. Until now, however, the idea was not implemented in eye-typing systems, even though it already found useful applications in other systems [3].

In this paper, we introduce an algorithm for adjustable dwell time closely related to the idea of adaptive control for typing speed.

This paper comprises two parts. First, we describe a pilot study to investigate the dynamics of user behavior during an eye-typing task. In particular, we were primarily interested in how long the gaze stayed on a key upon selection. The study also helped us in determining the coefficients of the algorithm's transfer function as well as the range of dwell time values best suited for users. Then, we present the algorithm along with a user study conducted to evaluate it.

EXIT TIME UPON KEY SELECTION

In this study we measured exit time upon selection of virtual keys. Exit time was defined as the time interval between the moment a key was selected and the moment the gaze left the key.

Two experimental conditions were compared. In the first condition, participants were asked to enter text the way they wanted. In the second condition, participants were told they could change the dwell time (and in effect, the typing speed) by manipulating the exit time: to bring the dwell time down, they had to gaze away from a key faster and vice versa. In fact, however, the software did not respond to participants' attempts to change the dwell time. This setup was chosen so that comparison of the two experimental conditions would yield an estimate on how fast the algorithm to be developed should react to changes in exit time.

Method

Participants

Nine unpaid volunteers (5 male, 4 female) participated in the experiment. All were employees at the University of Tampere aged 22 to 35. All were familiar with the QWERTY keyboard layout as they used the keyboard on daily basis.

Participants were assigned to two groups. The first group included five participants having some experience in eye typing. Everyone from this group had participated in at least five similar studies. The second group included four participants with no prior experience with eye trackers.

Equipment

A remote eye tracking system *iViewX*™ from SensoMotoric Instruments was used for collecting gaze data. Eye gaze input and associated events were recorded using experimental software developed in our laboratory. The software generated a virtual keyboard with QWERTY layout (Figure 1). The keyboard contained two space buttons (the unmarked buttons on the right).

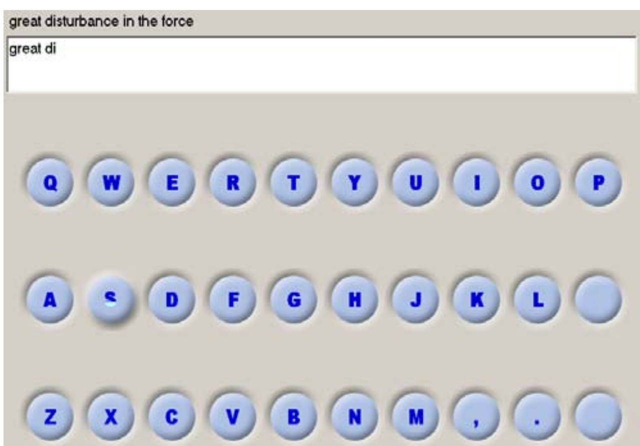

Figure 1. The virtual keyboard

Procedure

Participants were seated at a viewing distance of approximately 70 cm. After calibration of the eye tracker, they were given a couple of minutes to practice typing using their eyes. Then, the session began. Participants had to type phrases provided by the experimental software.

Each participant performed seven blocks of trials (one per each dwell time setting) in the first condition and four blocks in the second condition. A block included three phrases (approximately 90 characters) in the first condition and two phrases (approximately 60 characters) in the second condition. All trials were performed in one session lasting approximately half an hour per participant. The phrases to be entered were randomly retrieved from a set of 150 phrases. These phrases were taken from [4].

Design

Seven dwell time conditions were tested in the first experimental condition: 300, 400, 500, 600, 700, 900, and 1100 ms. Meanwhile, in the second experimental condition, four dwell time values were tested: 300, 500, 700, and 900 ms. Within each experimental condition, order of presenting the dwell time conditions was randomized among participants.

Results

The study showed that the novice participants had longer exit time than the experienced ones. On average, exit time tended to become shorter with dwell time decreasing from 500 to 300 ms, and stayed almost the same with dwell time increasing from 500 to 1100 ms (Figure 2).

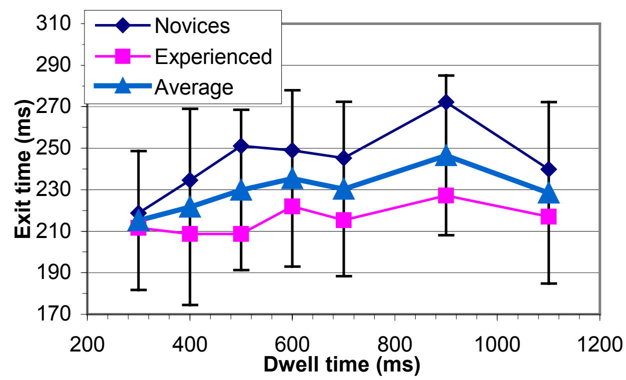

Figure 2. Exit time as a function of dwell time in the free typing condition (condition 1)

Exit times obtained in the second experimental condition are presented in Figure 3. Participants reported that they tried to decrease dwell time when it was 700 ms and 900 ms and to increase it for $DT = 300$ ms.

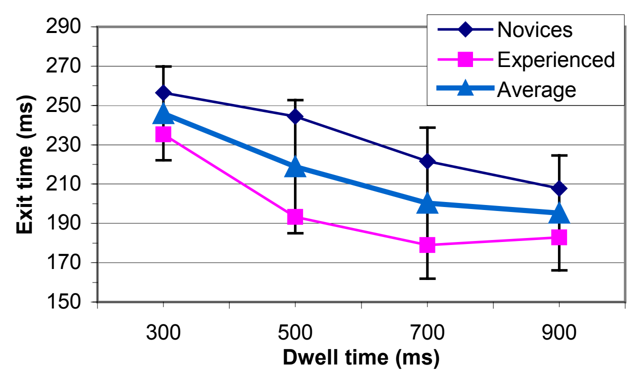

Figure 3. Exit time in attempt to control dwell time (condition 2)

Figure 4 shows the difference of exit times Δ_{RT} made by participants in the second (ET_2) and the first (ET_1) experimental conditions, respectively.

There was a clear attempt by participants to decrease the speed of "clicking" when dwell time was 300 ms. In the second experimental condition, participants prolonged their exit time by 31 ms on average, compared with exit time during typing without intention to control the speed of typing. There was also an evident attempt to speed up at $DT = 700$ ms and $DT = 900$ ms, with the difference amounting to 46 ms in the latter condition.

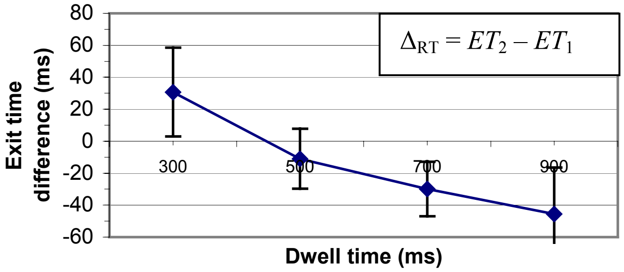

Figure 4. Difference in exit times

Error rates during typing were quite similar in both experimental conditions and did not exceed 5% for dwell time values in the range of 500 to 1100 ms. Error rate increased rapidly to 35%, however, when dwell time decreased to 300 ms (Figure 5).

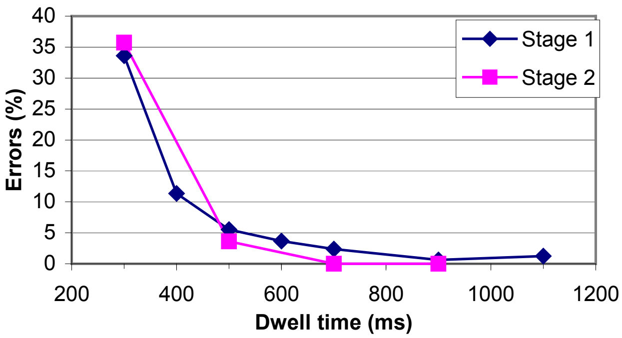

Figure 5. Error rates

Exit time showed some oscillation during the same block even when participants had no intention to change it. Figure 6 displays a typical pattern of variation in exit time.

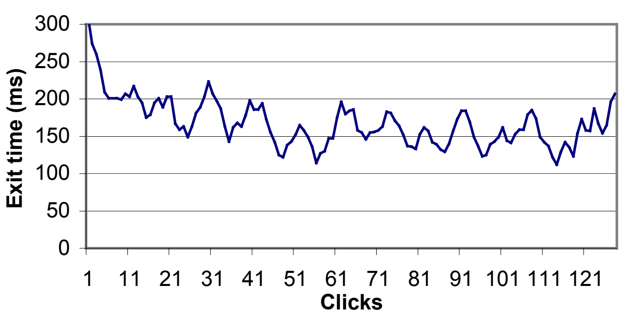

Figure 6. Variation in exit time (running average of five samples)

Participants reported that dwell time of 500±100 ms was most convenient for their work. Meanwhile, a change in dwell time by 100 ms was perceived as leading to significant inconveniences in typing.

Implications for Algorithm Design

Comparison of the exit times for the two experimental conditions shows that users are able to control their response to selection of virtual keys.

The algorithm should measure (for the first 30-50 clicks) the exit time using some predefined dwell time, and then use the obtained average as the threshold. To accommodate differences among users, the algorithm requires calibration. The calibration procedure would require users to type using, for instance, three or four dwell time values. This way the algorithm would map changes in exit time to the averaged user responses.

The unintended oscillation in exit time aggravates the task of algorithm design. The problem can be solved partly by increasing the number of averaged exit times. However, this number should not be too large as it could bring unacceptable delays in the update rate of dwell time.

Since dwell time of 300 ms brought many errors and was regarded as too small by all participants, the algorithm should prevent dwell time getting below 400 ms. On the other hand, typing with dwell time exceeding 700 ms is too slow. That is why the algorithm must keep dwell time inside some margins.

ALGORITHM FOR ADJUSTABLE DWELL TIME

The algorithm makes a decision on changing dwell time based on the difference between the exit time and the threshold TH. The algorithm records exit times during the first 40 selections of virtual keys. During this time, the initial dwell time DT_{REF} setting (600ms) does not change. Then, the average is obtained for the exit time. The threshold is assigned to this average value TH_{600}. After this, dwell time is adjusted according to the average value ET_{AVG10} of the last ten exit times. As revealed by Figure 4, a change by 10 ms in exit time causes a change in dwell time by 80ms:

$$DT = DT_{REF} + K_{ET2DT}(ET_{AVG10} - TH), \quad (1)$$

where $K_{ET2DT} = 80/10 = 8$.

Further, the algorithm calculates the average dwell time for every consecutive 30 selections and assigns the value to DT_{REF}. This way dwell time is updated at regular intervals during the entire typing process. In turn, changes in DT_{REF} affect the current threshold value. The threshold changes by 7 ms for every 100-ms change in DT_{REF}:

$$TH = TH_{600} - K_{DT2TH}(600 - DT_{REF}), \quad (2)$$

where $K_{DT2TH} = 0.075$. This value was determined empirically after performing a linear regression on the data presented in Figure 2. There was an increase in average exit time by approximately 30 ms with an increase in dwell time from 400 to 800 ms (30/400 = 0.075).

To check the efficiency of this algorithm, a new experiment was conducted.

Method

Participants and Equipment

Participants and equipment in this study were the same as in the pilot study.

Procedure

As in the previous study, participants had to type phrases provided by the experimental software. They were instructed to do this at a pace of their choice without paying attention to errors. Also, participants were informed that they could change the dwell time by varying the speed of gazing away from the selected button.

Design

Participants performed three blocks of trials in one session lasting approximately 20 minutes. Each block consisted of seven phrases (approximately 200 characters) to be entered.

Results

The average error rate was 2.3%, whereas the average typing speed was 12.1 words per minute.

Figure 7 displays the average dwell times obtained for each participant. These averages ranged from 450 to 600 ms, with the grand mean equal to 533 ms. This matches the range of dwell times reported as the most convenient by participants during the free typing condition in the pilot study.

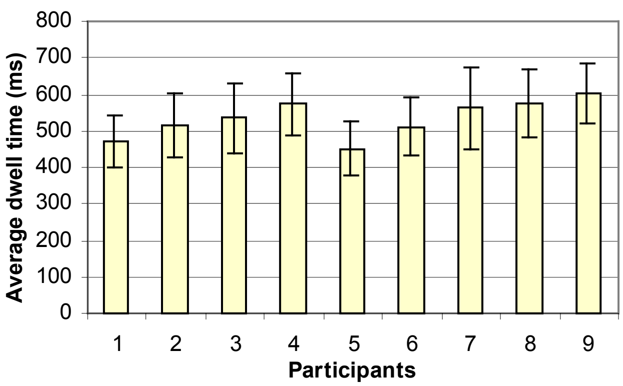

Figure 7. Average dwell times per participant

The error rate for typing facilitated through the adjustable dwell-time algorithm was consistent with that obtained for the first condition in the pilot study, so the algorithm did not impair the accuracy of typing. Meanwhile, the average typing speed corresponded to the typing speed obtained for the second condition in the pilot study with the dwell time equal to 560 ms.

CONCLUSION

The adjustable dwell time algorithm presented in this study allows increasing user comfort when performing the task of eye typing without sacrificing accuracy or typing speed.

In the questionnaire provided at the end of the experiment, participants stated that they were essentially satisfied with the algorithm's performance. On the other hand, participants pointed out that it was hard for them to change typing speed quickly as the system responded with a delay equal to approximately the entry time for one phrase.

Thus, the level of control over dwell time is not optimal yet. As mentioned before, the algorithm operates on the assumption that exit time changes by 10 ms to have a change in dwell time by 50 ms. Also, the threshold changes by merely 7.5 ms in response to a change in dwell time by as much as 100 ms. This is the primary reason why participants did not manage to change dwell time as quickly as they wished.

Another issue associated with adjustment of dwell time is involuntary variation in exit time. Upon selection of a key, users cannot respond to this event by gazing off equally fast each time, and even taking averages of the last ten samples for exit time cannot completely smooth its oscillations. In turn, this tends to make adaptive adjustment of dwell time less convenient for the user.

Therefore, a tradeoff on the extent of automatic control performed by the algorithm over dwell time would be an appropriate solution to this problem. Once the algorithm adjusts the dwell time to the level perceived as "convenient" by the user, the user could simply exit the automatic control mode by selecting, for instance, a dedicated key. This way the dwell time would remain constant for as long as the user is satisfied with its current value. The user could re-enter the automatic control mode at any time by pressing the same dedicated key again.

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