Dwell Time Reduction Technique using Fitts' Law for Gaze-Based Target Acquisition

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ABSTRACT

We present a dwell time reduction technique for gaze-based target acquisition. We adopt Fitts' Law to achieve the dwell time reduction. Our technique uses both the eye movement time for target acquisition estimated using Fitts' Law (T_e) and the actual eye movement time (T_a) for target acquisition; a target is acquired when the difference between T_e and T_a is small. First, we investigated the relation between the eye movement for target acquisition and Fitts' Law; the result indicated a correlation of 0.90 after error correction. Then we designed and implemented our technique. Finally, we conducted a user study to investigate the performance of our technique; an average dwell time of 86.7 ms was achieved, with a 10.0% Midas-touch rate.

CCS CONCEPTS

• **Human-centered computing** → **Interaction techniques**; *Pointing*;

KEYWORDS

Gaze interaction, eye tracking, dwell-based interaction, eye movement, ISO 9241, Midas-touch

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1 INTRODUCTION

Because the dwell time heavily limits the performance of dwell-based target acquisition technique, previous work attempted to minimize the dwell time and the number of Midas-touches [Jacob 1991] by adjusting the button size [Penkar et al. 2012], user and button type [Nayyar et al. 2017], and by using next-letter prediction for typing [Mott et al. 2017]. In this paper, we show another dwell time reduction technique for gaze-based target acquisition. Our technique uses Fitts' Law [Fitts 1954], which models the act of pointing and can estimate the time required for target acquisition. In our technique, a target is acquired when the difference between the eye movement time estimated by Fitts' Law and the actually measured eye movement time is smaller than a threshold value.

In this work, we first reinvestigated a relation between the eye movement for a target acquisition and Fitts' Law. The result showed that the correlation (r^2) between the eye movement time estimated by Fitts' Law and the measured eye movement time was 0.90 after error correction. We designed and implemented our technique according to this result. We conducted a user study to investigate the performance of our technique. The result showed that our technique reduced the average dwell time to 86.7 ms with a 10.0% Midas-touch rate.

The contributions of this paper are as follows: 1) the principle of dwell time reduction technique, 2) experimental results showing that the eye movement for target acquisition conforms to Fitts' Law, 3) implementation method of our technique, and 4) experimental results showing the performance of our technique.

2 RELATED WORK

Many gaze-based target acquisition techniques have been explored. Our technique is based on eye movement for target acquisition. Thus, we discuss previous work on the eye movement for target acquisition.

2.1 Gaze-Based Target Acquisition Techniques

[Jacob 1991] showed dwell-based target acquisition technique and defined the notion of Midas-touch in the context of gaze-based target acquisition. [Sibert and Jacob 2000] showed that the dwell-based technique is faster than that using a mouse. However, as previous work has reported, there is a trade-off between Midas-touches and constant dwell time. For example, in a pilot study by [Nayyar et al. 2017] of 192 target acquisitions, a 200 ms dwell time caused more than 50 Midas-touches and that of 300 ms caused more than 40 Midas-touches. Based on this result, the authors used 400 ms as the constant dwell time in their user study.

Because constant dwell time heavily limits the performance of dwell-based target acquisition, previous work has focused on reducing the dwell time by adjustment. [Penkar et al. 2012] adjusted it to button size. [Nayyar et al. 2017] adjusted it to each user and button type. [Mott et al. 2017] dynamically adjusted it by next-letter prediction for typing.

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As an approach to avoid Midas-touches, many gaze-based target acquisition techniques use the hand for *click* instead of dwell: [Liebling and Dumais 2014; Zhai et al. 1999] used a mouse; [Pfeuffer and Gellersen 2016; Stellmach and Dachselt 2012; Turner et al. 2015] used touch; and [Chatterjee et al. 2015] used hand gestures in mid-air for target acquisition. *Smooth pursuit* is another approach to avoid Midas-touches, in which the user acquires a target using only the eye by pursuing the moving target displayed near the target [Esteves et al. 2015; Schenk et al. 2017].

Dwell-free target acquisition techniques for text entry may provide faster target acquisition than dwell-based ones. Filteryedping [Pedrosa et al. 2015] is a dwell-free typing technique that predicts a word from a sequence of characters which the user glances at. EyeSwipe [Kurauchi et al. 2016] is also a dwell-free typing technique that uses "target reverse crossing" [Feng et al. 2014]; the user only has to gaze at the first and last characters of the word using "target reverse crossing", and to move the user's eye for the other characters. From the eye movement, EyeSwipe predicts the word.

By contrast, we focus on designing a general-purpose gaze-based target acquisition technique that allows the user to acquire a target quickly using only the eyes by dwell time reduction.

2.2 Analyses of Eye Movement in Gaze-Based Interaction

Eye movement for target acquisition has been explored extensively. [Zhang and MacKenzie 2007] evaluated the performance of dwell-based target acquisition using a multi-directional pointing task; they showed that the dwell-based one is faster than that using a mouse, although its throughput was lower.

Moreover, some studies have explored the relation between gaze-based target acquisition technique and Fitts' Law. [Ware and Mikaelian 1987] stated that vertical and horizontal target acquisition using eye movements conform to Fitts' Law based on their experimental results. [Miniotas 2000] derived an r^2 between the movement time and Index of Difficulty of Fitts' Law. In this experiment, a comparison of horizontal target acquisition using a mouse and the gaze showed that r^2 was 0.98 for both conditions. [Vertegaal 2008] evaluated the performance of four target acquisition techniques (mouse, stylus, gaze-based with a manual click, and dwell-based one) in horizontal target acquisition; r^2s were reported: 0.99 for the mouse, 0.98 for the stylus, 0.88 for gaze-based with a manual click, and 0.89 for dwell-based one. [Murata et al. 2015] evaluated the relation between gaze-based interactions with various target shapes and eight directions, and Fitts' Law; they found a generalized Fitts' Law model which well fits their experimental data with $r^2 = 0.8776–0.9965$.

In our work, we use a multi-directional pointing task to investigate the relation between eye movement for target acquisition and Fitts' Law for designing and implementing our dwell time reduction technique.

3 PRINCIPLE

Our dwell time reduction technique for gaze-based target acquisition is based on Fitts' Law, as given by Equation 1 [MacKenzie 1989], to recognize whether the eye movement is for the target acquisition or not:

$$T = a + b \log_2(D/W + 1), \tag{1}$$

where T is the movement time for moving the pointer to the target; W is the width of the target; D is the distance to the target; and a and b are coefficients that depend on the user and the device. The term $\log_2(D/W + 1)$ is referred to as Index of Difficulty (ID), which shows the difficulty of target acquisition.

Assume that an eye movement conforms to Fitts' Law. Under this assumption, if the user moves the gaze from point (P) to an on-screen icon to acquire it, the eye movement time, width of the icon, and distance from P to the icon satisfy Equation 1. Thus, we can determine whether an eye movement is for target acquisition or not by testing weather these three variables satisfy Equation 1, when the gaze enters the icon.

The above test can be implemented using threshold-based approach (Figure 1). First, a calibration is performed to obtain a and b in Equation 1. At runtime, when the eye movement slows and the gaze enters the icon, we estimate the movement time (T_e) using Equation 1. If the difference between T_e and the actual eye movement time (T_a) is smaller than a threshold value (τ), we regard the icon as the target icon; otherwise, we regard the icon as a non-target icon (Figure 1a). On the other hand, when the gaze enters the icon while the eye movement is speeding up or is fast, we regard the icon as a non-target icon, even if the difference is smaller than τ (Figure 1b). Thus, the Midas-touch problem is remedied by examining both the speed of the eye movement and the difference between T_e and T_a. However, in the case of short distance between non-target and target icons, the gaze may slowly enter the non-target icon; if the difference between T_a and T_e is small, Midas-touch may occur (Figure 1c).

In contrast to previous dwell-based target acquisition techniques, our technique reduce the dwell time because the target icon is acquired immediately when the gaze enters the icon.

4 EXPERIMENT 1

To implement our technique, we conducted an experiment (Experiment 1) to verify whether the eye movement for target acquisition conforms to Fitts' Law.

4.1 Methods

16 participants (all male) were recruited for Experiment 1. Their age ranged from 21 to 24 years ($M = 22.0$). The participants had normal or corrected (glasses or contact lenses) vision with no color vision abnormalities; five wore glasses and four wore contact lenses. None had ever used an eye tracker.

We used Tobii EyeX [Tobii AB 2017] in the experiment, which was attached to the bottom of a 24-inch non-glare type display, to prevent reflection; with the resolution of the display was 1,920 × 1,080 pixels. The participant's head was positioned 60 cm away from the display, which was attached to a height-adjustable arm to allow adjustment of the positional relation between the participant and the display. The display was placed in front of a white wall to prevent interference from objects unrelated to the experiment. Experiment 1 was conducted in a room lit by a LED fluorescent lamp to ensure consistent lighting condition.

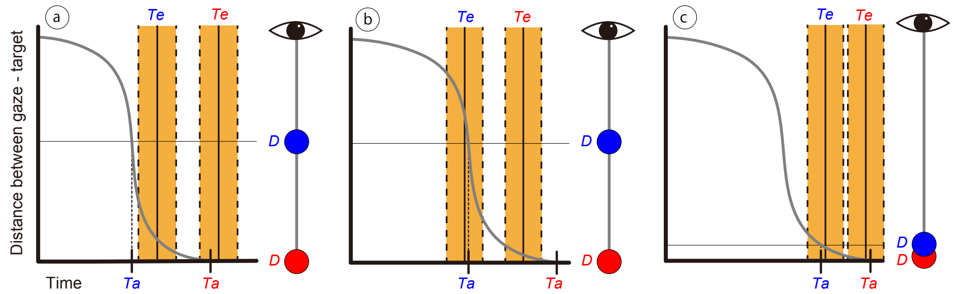

Figure 1: Principle of our technique. The gray line represents the eye movement trajectory. The orange region represents the threshold range ($T_e \pm \tau$). The Red circle represent target icon. Blue circles represent a non-target icons. a) Target icon is acquired. b) No target is acquired. c) Non-target is acquired (Midas-touch).

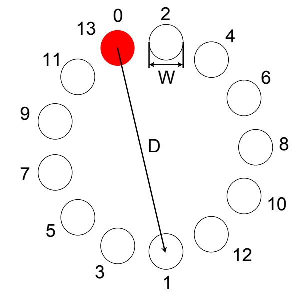

Figure 2: Multi-directional pointing task. The red circle is the target and the number shows the order of targets.

A multi-directional pointing task (Figure 2) introduced in ISO 9241-411 [ISO 2012] was used. We used five conditions in each for target distance (D: 2.00, 4.00, 6.00, 8.00, 10.0 inches) and target width (W: 1.00, 1.25, 1.50, 1.75, 2.00 inches).

The participants were required to look at targets on the screen in each trial. Each task comprised 13 trials. Within a session, the participant performed 25 tasks (5 distance conditions × 5 target width conditions) and five sessions were conducted. In total, we collected data for 26,000 trials (16 participants × 13 trials × 25 tasks × 5 sessions).

Once the participant's gaze had entered the target, the eye movement time was recorded. The target then converted to the background color, and the next target was displayed immediately. The order of the combination of W and D was randomized for each session.

The participants were asked to look consciously at the center of the target as quickly as possible. The participants were also asked not to move their head as much as possible, given that the performance of the eye tracker is less robust with head movement. Prior to the session, the eye tracker was calibrated. The calibration was performed as many times as necessary by adjusting the positional relation between the participant and the eye tracker using a height-adjustable arm.

Before the experiment, questionnaires were used to obtain the demographic information of the participants and their fatigue status; fatigue was evaluated by a 5-point Likert scale. The task began when the participant pushed the 'Enter' key on the keyboard placed by participant's hand. After looking at all 13 targets, the participants were asked to take a rest if desired to reduce the effect of the participant's eye fatigue. The participants were also asked to complete a fatigue questionnaire, and took a rest at least five minutes. The next task began by pushing the 'Enter' key. Experiment 1 took approximately 55 minutes per participant. Each participant received 820 JPY (approximately eight USD).

4.2 Results and Analysis

A Wilcoxon signed-rank test showed that there was no significant difference between fatigue before the experiment and after each session ($p > 0.05$). No participants stated that they were fatigued after the experiment. However, the results indicated apparent misrecognition due to eye tracking problems. Therefore, before testing whether the eye movement for target acquisition conformed to Fitts' Law, we first examined the results to correct for misrecognition.

4.2.1 Error Correction. We found that the movement time in some trials was unrealistically long, which we call misrecognized trials. Figure 3 shows the relations between time and gaze–target distance of a misrecognized trial (red line) and a successful trial (blue line) of a participant. In this misrecognized trial, the participant looked at the target once; however, the gaze was recognized to fall outside of the target (i.e., misrecognition). Therefore, the participant then looked at the target again, and then the gaze was recognized to be within the target. In fact, the participant commented, "I felt that my gaze was not recognized appropriately. When this occurred, I first looked at different area apart from the target, and then looked at the target again. This time the gaze was recognized".

We corrected this misrecognition by referenced to the following two observations. (1) The gaze–target distance was shortened markedly, and the distance reduction rate decreased, in both the misrecognized and successful trials (green region in Figure 3). (2) The gaze–target distance was stable for a while after the distance reduction rate decreased, in misrecognized trials (yellow region in Figure 3); we assumed that this period was a fixation on the target. Based on these observations, we took the time from the beginning of an eye movement to the beginning of the fixation as the movement time. The period of fixation was defined at 100 ms in this error correction.

4.2.2 Correlation. The overall r^2 between T_e and T_a was 0.68 for the original data and 0.90 for the corrected data. There was a significant difference between the original and corrected data with a Mann-Whitney test ($p < 0.05$).

We performed a Smirnov-Grubbs test with 95% confidence interval (CI) to assess the difference between T which was estimated using a and b in the corrected data, and T_a in each ID. As the result, three combinations of W and D were detected as outliers: $W \times D = 2.00 \times 2.00$ inches, 2.00×4.00 inches, and 1.75×4.00 inches; these results are consistent with the findings of Drewes ([Drewes 2010a], p. 68). Therefore, we derived r^2 excluded four conditions

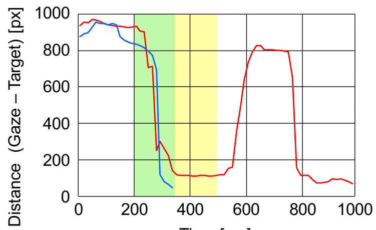

Figure 3: Relation between time and gaze–target distance. The red line shows a misrecognized trial. The blue line shows a successful trial. The green region shows the period during which the gaze approaches the target. The yellow region is the fixation period.

(W = 2.00 and 1.75 inches and D = 2.00 and 4.00 inches) to derive an r^2 of 0.95.

5 IMPLEMENTATION

To obtain T_e and T_a, we use an eye movement detection system. A calibration system is used to derive the constants of Equation 1.

5.1 Eye Movement Detection

Eye movement detection is used to acquire the target regardless of the original gaze point estimated by the eye tracker. The distance to the target, D, used to calculate T_e is calculated starting from the point at which the gaze first moved towards the target center. T_a corresponds to time between the gaze beginning to move and the gaze entered the target. We use the eye movement distance from the gaze point of one sample before for the eye movement detection. We define four eye movement states: *fixation*, *start of movement*, *movement*, and *end of movement*. These states are defined with the same mechanism discussed in Section 4.2.1.

First, the *fixation* state corresponds to when the eye movement distance is shorter than short distance (d_s). The eye movement state is *start of movement* when the eye movement distance exceeds d_s during *fixation*; additionally, *fixation* can occur again if the eye movement distance is shorter than d_s during *start of movement*. Then, the eye movement state is *movement* when the eye movement distance exceeds long distance (d_l) during *start of movement*. Finally, the eye movement state is *end of movement* when the eye movement distance is shorter than d_l during *movement*. The eye movement state is *fixation* when the eye movement distance is shorter than d_s during *end of movement*. During *end of movement* or *fixation* after *end of movement*, a comparison of T_e and T_a is performed to test whether the eye movement is for target acquisition or not.

With this implementation, if the gaze passes a non-target icon in *movement*, the comparison is not performed (same as the icon in Figure 1b) and thus, Midas-touches are avoided. However, if the gaze passes a non-target icon in *end of movement* or *fixation* after *end of movement*, the comparison is performed and thus Midas-touches potentially occur.

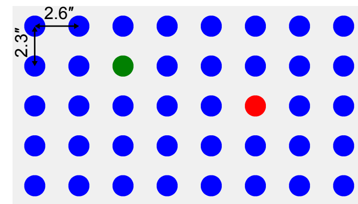

Figure 4: Display used in Experiment 2. The red circle is a target. The blue circles are non-targets. The green circle is an acquired circle.

5.2 Calibration for Deriving Constants

Our technique requires that the constants of Equation 1 be derived for each user and each device beforehand. To do this, we adopt the same multi-directional pointing task used in Experiment 1 for the calibration. Currently, this calibration is performed using three conditions for W (1.00, 1.25, and 1.50 inches) and D (6.00, 8.00, and 10.0 inches); note that these conditions remained after the outliers which is detected in Section 4.2.2 were removed in Experiment 1.

6 EXPERIMENT 2

We conducted a user study (Experiment 2) to investigate the dwell time and Midas-touch rate of our technique, which were then compared to the previous dwell-based target acquisition technique (hereinafter, previous technique). We assumed a 400 ms dwell time for the previous technique, which is the dwell time used by OptiDwell [Nayyar et al. 2017].

6.1 Methods

17 participants (P1–P17; all male) were recruited for Experiment 2. Their age ranged from 20 to 24 years (M = 22.0). Eight (P1–P8) did not wear glasses or contact lenses; seven (P9–P14, P17) wore glasses; and two (P15, P16) wore contact lenses. One participant (P16) had abnormal color vision and eight (P1–P5, P10, P11, and P15) had also participated in Experiment 1; thus, these participants had previous experience with eye tracker and the others did not.

The same eye tracker and display used in Experiment 1 were used in Experiment 2. In Experiment 1, we were unable to stabilize the performance of Tobii EyeX due to head movement of the participants. Moreover, the participant commented, "It was difficult to prevent head movement". Thus, we used a chin rest in Experiment 2 to minimize head movement. The other experimental conditions, such as lighting condition, were the same as Experiment 1.

In Experiment 2, for each trial, participants were asked to acquire one target from 40 circles were arranged in a 5 × 8 gird (Figure 4). Each task included 40 target acquisition (i.e., 40 trials). The target circles were presented in a random order. Three target width were used to investigate the effect of target width on the performance of our technique. In each session, the participants performed three tasks, one for each target width (1.00, 1.25, and 1.50 inches). To reduce order effects, we divided the participants into two groups of eight participants. One group began with our technique; another began with the previous technique. The participants performed two sessions with each technique. In total, 3,840 trials (40 trials × 3

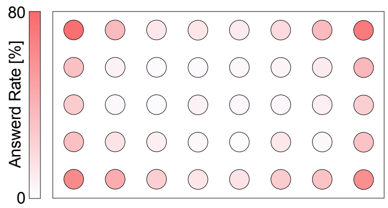

Figure 5: Questionnaire result regarding target locations that are difficult to acquire. Deeper color shows more difficult target locations.

tasks × 2 sessions × 16 participants) of data were collected for each technique.

Before the experiment, we used the results of Experiment 1 to determine τ using the following equation:

$$\tau = 0.031 + 0.024 \log_2(D/W + 1). \quad (2)$$

The constants in Equation 2 were based on SD of the error-corrected result ($a = 0.031, b = 0.024$). D was the calculated by using the mechanism discussed in Section 5.1.

We asked the participants to look at the target as quickly and consciously as possible, and to keep looking at the target until the target was acquired. When a circle was acquired (even when it was a non-target circle), it turned green. If the target was correctly acquired, or if it was not acquired after more than five seconds, the target turned green and then the next target appeared. In Experiment 2, two calibrations were performed: one for Tobii EyeX and one for our technique. The participant performed the calibration of Tobii EyeX before each task; this calibration was done more than once and in the same way as for Experiment 1. Another calibration, i.e., that for our technique, was conducted before each session: when r^2 was higher than 0.90 (i.e., the error-corrected result), we used a and b derived from the calibration; in all other cases, the participant repeated the calibration of our technique.

The participants were asked to rest more than one minute between tasks to reduce eye fatigue; more than one minute of rest was also taken after the calibration of our technique. After a session, the participant was asked to complete a questionnaire regarding their impression, target locations that were difficult to acquire, and eye fatigue using a five-point Likert scale. Then, we asked the participants to remove their head from the chin rest to take a rest of more than five minutes. After all sessions, the participant were asked to complete a questionnaire that asked, "Which technique did you feel fatigue with?" with reasons in a free-form text. Experiment 2 took approximately 83 minutes per participant. Each participant received 1,640 JPY (approximately 15 USD).

6.2 Results

We performed a Wilcoxon signed-rank test ($\alpha = 0.05$) on the fatigue scores: there was a significant difference between both techniques in the first session and no significant difference between them in the second session.

During the experiment, the gaze estimated by Tobii EyeX for one participant who wore glasses (P17) was seriously dispersed even though calibration of Tobii EyeX was successful. Thus, the results for P17 were excluded and we used those from the remaining 16 participants. We also classified the trials into three categories for the analyses: successful, Midas-touch, and failed trials. A successful trial was obtained when the target was acquired with no Midas-touches. A Midas-touch trial was obtained when a non-target circle was acquired and a failed trial was obtained when no circle was acquired within five seconds. The results showed that there were 6,284, 368, and 1,028 of the successful, Midas-touch, and failed trials, respectively. Questionnaire results are shown in Figure 5; the outermost border of the grid (especially the four corners) were answered, which is consistent with [Feit et al. 2017]. Moreover, both P15 and P16 who wore contact lenses commented, "I have dry eye syndrome and it was difficult to keep my eyes open and look at the target continuously". Therefore, we investigated variation in performance by vision condition (normal or corrected) of the eye, as described in the following sections.

6.2.1 *Dwell Time.*

We calculated the dwell time, of the successful trials of our technique, as the time between the gaze entering the target and acquisition of the target (Figure 6, left). The dwell time was 86.7 ms ($SD = 24.2$) using our technique and 409 ms[1] ($SD = 1.38$) using the previous technique. Therefore, our technique reduced the dwell time by 78.8%.

With respect to vision condition of the eye, the dwell time was 98.1 ms ($SD = 25.1$) under normal vision conditions and 75.3 ms ($SD = 16.6$) under corrected vision conditions. There was no significant difference between normal and corrected vision conditions with a Mann-Whitney test ($p > 0.05$).

The left of Figure 7 shows the dwell time by target width conditions using our technique: 78.8 ms ($SD = 23.9$) at 1.00 inch, 91.7 ms ($SD = 26.1$) at 1.25 inches, and 89.6 ms ($SD = 28.4$) at 1.50 inches. We performed Wilcoxon signed-rank tests ($\alpha = 0.05$); the results showed that there was a significant difference between 1.00 and 1.25 inches, and no significant difference between any other pair.

6.2.2 *Midas-touch Rate.*

We calculated the Midas-touch rate of our technique as the total number of Midas-touch trials divided by the sum of the number of successful and Midas-touch trials (Figure 6, right). The rate was 10.0% ($SD = 4.76$) using our technique and 0.70% ($SD = 0.79$) using the previous technique.

With respect to vision condition of the eye, the Midas-touch rate was 6.10% ($SD = 2.84$) under normal vision conditions and 14.0% ($SD = 2.47$) under corrected vision conditions. There was a significant difference between normal and corrected vision conditions with a Mann-Whitney test ($p < 0.05$).

The right of Figure 7 shows the Midas-touch rate by target width conditions in our technique: 7.26% ($SD = 4.29$) at 1.00 inch, 8.32% ($SD = 5.95$) at 1.25 inches, and 14.3% ($SD = 9.24$) at 1.50 inches. We performed Wilcoxon signed-rank tests ($\alpha = 0.05$); the results showed that there was a significant difference between 1.50 inches and smaller target width conditions and no significant difference between 1.00 and 1.25 inches.

[1]Even though we used 400 ms as the dwell time in the previous technique, it was 409 ms, since the sampling rate of Tobii EyeX was 60 Hz, which involves at least 16 ms of errors.

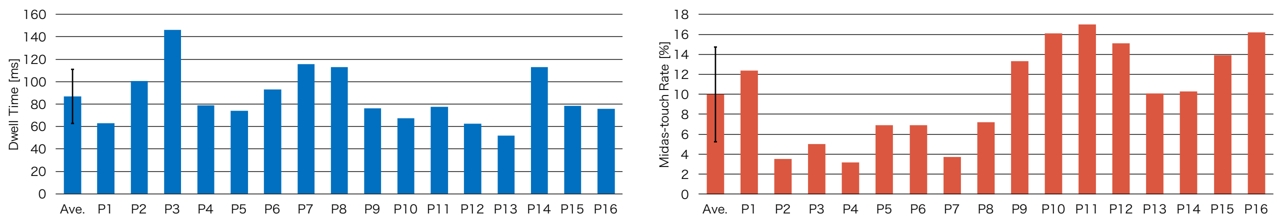

Figure 6: Performance of our technique. Left: dwell time; right: Midas-touch rate. Error bars indicate ± one SD.

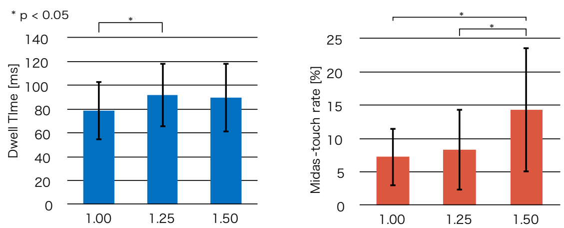

Figure 7: Performance by target width condition. Left: dwell time; right: Midas-touch rate. Error bars indicate ± one SD.

6.3 Discussions

[Nayyar et al. 2017] reported a Midas-touch rate of 26.0% using a 200 ms dwell time; however, we achieved a considerable dwell time reduction at a low Midas-touch rate, although this comparison is not appropriate because the conditions of both experiments were different. With respect to target width conditions, the largest circle was caused the highest Midas-touch rate (Figure 7, right). In the case of largest circle, the gaze point estimated by the eye tracker tended to enter circle due to dispersion of the estimated gaze. Additionally, the distances between the point of *start of movement* and the circles neighboring the target were nearly the same as that of the target (i.e., T_es were nearly the same), such that the Midas-touch trials occurred when the estimated gaze entered the neighboring circles. Given that the Midas-touch rate was lowest under the largest target condition, and that the smallest target condition caused the highest number of failed trials (1.00 inches: 18.0%; 1.25 inches: 9.30%; 1.50 inches: 7.19%), 1.25 inches was considered the most suitable target width, although 1.00 inch could also be used if the performance of the eye tracker improves.

Some participants (two in Experiment 1 and one in Experiment 2) commented that "I felt that the target was acquired before I looked at the target". This suggests that too short dwell time (e.g., 0 ms) is not suitable for dwell-based target acquisition. We plan to conduct a user study to establish optimal dwell time. Moreover, as many trials in which circles were presented towards the outermost border of the grid were failed, as described above, the middle of the display is most appropriate with respect to target position.

Regarding the questionnaire of "Which technique did you feel fatigue with?", four participants answered the previous technique, three answered our technique, and eleven answered no difference. Two participants in Experiment 2 commented that "I felt that your technique was more tired than the previous technique, due to the necessity of calibration of your technique". In Experiment 2, calibration of our technique used nine combinations (three $D \times$ three W). To reduce the fatigue associated with the calibration of our technique, we plan to use smaller number of combinations with widely distributed IDs (e.g., four combinations whose IDs are 1.00, 2.00, 3.00, and 4.00).

7 LIMITATIONS AND FUTURE WORK

In the results of Experiment 1, gaze-based target acquisition highly conformed to Fitts' Law. However the participants had similar characteristics (16 healthy young men). Additionally, in Experiment 2, one participant (P16) had abnormal color vision. P16 commented, "I have color vision abnormalities. So, it was difficult to move my gaze from a green circle to a red circle when these circles were neighboring". Therefore, we need to evaluate r^2 and the performance of our technique with more various attributes: women, younger and older individuals, and people with neurodegenerative diseases (e.g., amyotrophic lateral sclerosis).

Moreover, some modified Fitts' Law coping with different conditions were proposed: target shape [Hoffmann and Sheikh 1994; Murata et al. 2015] and pointer movement direction [Murata et al. 2015]. We plan to examine whether these models conform to our technique. Furthermore, we will modify our technique to dynamically select the most appropriate model, depending on the conditions, to improve the performance.

Although some previous studies have shown that the eye movement conforms to Fitts' Law [Miniotas 2000; Ware and Mikaelian 1987], which is consistent with our results, [Drewes 2010a,b] reported that the eye movement would not conform to Fitts' Law. Moreover, [Carpenter 1988] showed that eye movement conforms to the formula that is independent of target width. Therefore, it is necessary to further investigate the relation between eye movement and Fitts' Law and other formulas in more detail.

8 CONCLUSION

We presented a dwell time reduction technique for gaze-based target acquisition based on Fitts' Law. Our technique used both the eye movement time for target acquisition estimated using Fitts' Law and the actual eye movement time for target acquisition. In our technique, a target is acquired when the time difference between the estimated and actual eye movements is small. Based on the results of the user study for investigating the performance of our technique; an average dwell time of 86.7 ms was achieved, with a 10.0% Midas-touch rate.

REFERENCES

Roger Hugh Stephen Carpenter. 1988. *Movement of the Eyes 2nd Edition Revised and Enlarged*.

Ishan Chatterjee, Robert Xiao, and Chris Harrison. 2015. Gaze+Gesture: Expressive, Precise and Targeted Free-Space Interactions. In *Proceedings of the 2015 ACM on International Conference on Multimodal Interaction (ICMI '15)*. ACM, New York, NY, USA, 131–138. https://doi.org/10.1145/2818346.2820752

Heiko Drewes. 2010a. Eye Gaze Tracking for Human Computer Interaction. https://edoc.ub.uni-muenchen.de/11591/. (2010). (accessed 2018-1-26).

Heiko Drewes. 2010b. Only One Law Formula Please!. In *Proceedings of the 28th SIGCHI Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '10)*. ACM, New York, NY, USA, 2813–2822. https://doi.org/10.1145/1753846.1753867

Augusto Esteves, Eduardo Velloso, Andreas Bulling, and Hans Gellersen. 2015. Orbits: Gaze Interaction for Smart Watches using Smooth Pursuit Eye Movements. In *Proceedings of the 28th Annual ACM Symposium on User Interface Software and Technology (UIST '15)*. ACM, New York, NY, USA, 457–466. https://doi.org/10.1145/2807442.2807499

Anna Maria Feit, Shane Williams, Arturo Toledo, Ann Paradiso, Harish Kulkarni, Shaun Kane, and Meredith Ringel Morris. 2017. Toward Everyday Gaze Input: Accuracy and Precision of Eye Tracking and Implications for Design. In *Proceedings of the 35th SIGCHI Conference on Human Factors in Computing Systems (CHI '17)*. ACM, New York, NY, USA, 1118–1130. https://doi.org/10.1145/3025453.3025599

Wenxin Feng, Ming Chen, and Margrit Betke. 2014. Target Reverse Crossing: A Selection Method for Camera-based Mouse-replacement Systems. In *Proceedings of the 7th International Conference on PErvasive Technologies Related to Assistive Environments (PETRA '14)*. ACM, New York, NY, USA, Article 39, 4 pages. https://doi.org/10.1145/2674396.2674443

Paul. M. Fitts. 1954. The Information Capacity of the Human Motor System in Controlling the Amplitude of Movement. *Journal of Experimental Psychology* 74 (1954), 381–391.

Errol R. Hoffmann and Ilyas H. Sheikh. 1994. Effect of Varying Target Height in a Fitts' Movement Task. *Ergonomics* 37, 6 (1994), 1071–1088. https://doi.org/10.1080/00140139408963719

ISO. 2012. *Ergonomics of human-system interaction – Part 411: Evaluation methods for the design of physical input devices*. International Organization for Standardization ISO/TS 9241-411.

Robert J. K. Jacob. 1991. The Use of Eye Movements in Human-computer Interaction Techniques: What You Look at is What You Get. *ACM Transaction on Information Systems* 9, 2 (1991), 152–169. https://doi.org/10.1145/123078.128728

Andrew Kurauchi, Wenxin Feng, Ajjen Joshi, Carlos Morimoto, and Margrit Betke. 2016. EyeSwipe: Dwell-free Text Entry Using Gaze Paths. In *Proceedings of the 34th SIGCHI Conference on Human Factors in Computing Systemss (CHI '16)*. ACM, New York, NY, USA, 1952–1956. https://doi.org/10.1145/2858036.2858335

Daniel J. Liebling and Susan T. Dumais. 2014. Gaze and Mouse Coordination in Everyday Work. In *Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing: Adjunct Publication (UbiComp '14 Adjunct)*. ACM, New York, NY, USA, 1141–1150. https://doi.org/10.1145/2638728.2641692

Ian Scott MacKenzie. 1989. A Note on the Information-Theoretic Basis for Fitts' Law. In *Journal of Motor Behavior (21)*. 323–330.

Darius Miniotas. 2000. Application of Fitts' Law to Eye Gaze Interaction. In *Proceedings of the 18th SIGCHI Conference Extended Abstract on Human Factors in Computing Systems (CHI EA '00)*. ACM, New York, NY, USA, 339–340. https://doi.org/10.1145/633292.633496

Martez E. Mott, Shane Williams, Jacob O. Wobbrock, and Meredith Ringel Morris. 2017. Improving Dwell-Based Gaze Typing with Dynamic, Cascading Dwell Times. In *Proceedings of the 35th SIGCHI Conference on Human Factors in Computing Systems (CHI '17)*. ACM, New York, NY, USA, 2558–2570. https://doi.org/10.1145/3025453.3025517

Atsuo Murata, Ippei Konishi, Makoto Moriwaka, and Daichi Fukunaga. 2015. Fitts' Modeling of Pointing Time in Eye-gaze Input System that Takes into Account the Effects of Target Shape and Display Location on Pointing Performance. *Procedia Manufacturing* 3, Supplement C (2015), 5358–5365. https://doi.org/10.1016/j.promfg.2015.07.646

Aanand Nayyar, Utkarsh Dwivedi, Karan Ahuja, Nitendra Rajput, Seema Nagar, and Kuntal Dey. 2017. OptiDwell: Intelligent Adjustment of Dwell Click Time. In *Proceedings of the 22nd International Conference on Intelligent User Interfaces (IUI '17)*. ACM, New York, NY, USA, 193–204. https://doi.org/10.1145/3025171.3025202

Diogo Pedrosa, Maria da Graça Pimentel, and Khai N. Truong. 2015. Filteryedping: A Dwell-Free Eye Typing Technique. In *Proceedings of the 33rd SIGCHI Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '15)*. ACM, New York, NY, USA, 303–306. https://doi.org/10.1145/2702613.2725458

Abdul Moiz Penkar, Christof Lutteroth, and Gerald Weber. 2012. Designing for the Eye: Design Parameters for Dwell in Gaze Interaction. In *Proceedings of the 24th Australian Computer-Human Interaction Conference (OzCHI '12)*. ACM, New York, NY, USA, 479–488. https://doi.org/10.1145/2414536.2414609

Ken Pfeuffer and Hans Gellersen. 2016. Gaze and Touch Interaction on Tablets. In *Proceedings of the 29th Annual Symposium on User Interface Software and Technology (UIST '16)*. ACM, New York, NY, USA, 301–311. https://doi.org/10.1145/2984511.2984514

Simon Schenk, Marc Dreiser, Gerhard Rigoll, and Michael Dorr. 2017. GazeEverywhere: Enabling Gaze-only User Interaction on an Unmodified Desktop PC in Everyday Scenarios. In *Proceedings of the 35th SIGCHI Conference on Human Factors in Computing Systems (CHI '17)*. ACM, New York, NY, USA, 3034–3044. https://doi.org/10.1145/3025453.3025455

Linda E. Sibert and Robert J. K. Jacob. 2000. Evaluation of Eye Gaze Interaction. In *Proceedings of the 18th SIGCHI Conference on Human Factors in Computing Systems (CHI '00)*. ACM, New York, NY, USA, 281–288. https://doi.org/10.1145/332040.332445

Sophie Stellmach and Raimund Dachselt. 2012. Look & Touch: Gaze-supported Target Acquisition. In *Proceedings of the 30th SIGCHI Conference on Human Factors in Computing Systems (CHI '12)*. ACM, New York, NY, USA, 2981–2990. https://doi.org/10.1145/2207676.2208709

Tobii AB. 2017. Tobii EyeX for PC Gaming. https://tobiigaming.com/product/tobii-eyex/. (2017). (accessed 2018-1-26).

Jayson Turner, Jason Alexander, Andreas Bulling, and Hans Gellersen. 2015. Gaze+RST: Integrating Gaze and Multitouch for Remote Rotate-Scale-Translate Tasks. In *Proceedings of the 35th SIGCHI Conference on Human Factors in Computing Systems (CHI '15)*. ACM, New York, NY, USA, 4179–4188. https://doi.org/10.1145/2702123.2702355

Roel Vertegaal. 2008. A Fitts' Law Comparison of Eye Tracking and Manual Input in the Selection of Visual Targets. In *Proceedings of the 10th International Conference on Multimodal Interfaces (ICMI '08)*. ACM, New York, NY, USA, 241–248. https://doi.org/10.1145/1452392.1452443

Colin Ware and Harutune H. Mikaelian. 1987. An Evaluation of an Eye Tracker As a Device for Computer Input. In *Proceedings of the SIGCHI/GI Conference on Human Factors in Computing Systems and Graphics Interface (CHI '87)*. ACM, New York, NY, USA, 183–188. https://doi.org/10.1145/29933.275627

Shumin Zhai, Carlos Morimoto, and Steven Ihde. 1999. Manual and Gaze Input Cascaded (MAGIC) Pointing. In *Proceedings of the 17th SIGCHI Conference on Human Factors in Computing Systems (CHI '99)*. ACM, New York, NY, USA, 246–253. https://doi.org/10.1145/302979.303053

Xuan Zhang and Ian Scott MacKenzie. 2007. Evaluating Eye Tracking with ISO 9241 - Part 9. In *Proceedings of the 12th International Conference on Human-computer Interaction: Intelligent Multimodal Interaction Environments (HCI '07)*. Springer-Verlag, Berlin, Heidelberg, 779–788. http://dl.acm.org/citation.cfm?id=1769590.1769678