Filling Linear Grids in Presence or Absence of Displayed Grids

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Abstract: In pixel art, users draw pictures by filling grids with colors. If a user's stroke deviates from the desired pixels, undesired pixels are filled with a wrong color. Thus, the users must draw strokes in a path created by the desired pixels. Depending on applications and settings, the grids are not always displayed, so the users sometimes must use paths with unclear widths. In this study, we conduct an experiment where participants fill various-size grids with and without the grids being displayed. We found that when the grids are not displayed or its size is small, the error rate is high. Additionally, the grid-filling tasks can be considered as steering tasks, and we found that the steering law holds even if the grids are not displayed. Thus, we believe that steering models are useful for defining the difficulty of the grid-filling tasks. We also discuss further experiments on grid-filling tasks.

1. Introduction

Steering operations in graphical user interfaces (GUIs) require users to move the cursor continuously in a path of a certain width and length without deviating from the path. Examples of such operations include navigating in hierarchy menus and selecting multiple objects with lassoing tools. The movement time of steering operations can be predicted by the steering law [1], and the steering law can be applied to many path shapes [1–4] and input devices [5–8].

In this paper, we introduce the steering law in a situation that has never been examined before: filling the grids. For example, in pixel art, users draw pictures by filling the grids with colors. When the user wants to complete a picture like the one in Fig. 1b, a simple way is to draw two blue straight lines (Fig. 1a). However, if the user's stroke deviates from the desired pixels, undesired pixels are filled in a wrong color. If the users accidentally fill undesired pixels in a wrong color, they must undo the operation and redo it, or overwrite the pixels in a correct color. That is, the users are required to draw strokes in a path created by the desired pixels.

In Super Mario Maker 2 for Nintendo Switch software, users can make Super Mario courses with a stylus (or finger) on the screen of the Switch[*1]. In the same software, users complete the course by filling the grids with blocks or enemies (Fig. 1c). However, if the user's stroke deviates

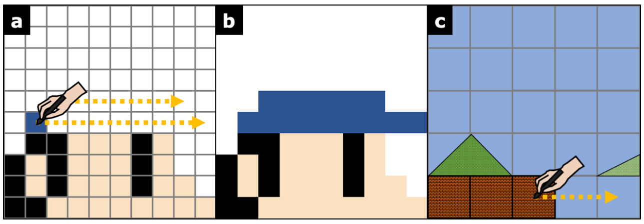

Fig. 1 (a) Drawing blue straight lines with grids. (b) Completion drawing without grids. (c) Game course making with grids.

from the grids, the blocks are placed in undesired positions. In summary, users must fill only the desired grids, following a path shown by the grids, and this operation is considered as one of the steering operations.

Depending on the application, the grids may be displayed or not. In Super Mario Maker 2, grids are always displayed for creating courses; however, in Microsoft Paint, where users can draw pictures of pixel art, grids are never displayed. On the other hand, in many pixel art applications such as Pixilart[*2], users can select whether the grids are displayed or not. The grids support users' operations because they clarify the drawing path. However, the impression of a pixel art picture is different depending on the presence or absence of grids, so some people may dislike the display of the grids.

Many steering studies focus on a clearly drawn path. However, in pixel art, depending on applications or settings, the steering path is not drawn if the grids are not displayed. In addition, users perform grid-filling operations on various devices, e.g., PC, Tablet, or Switch, so the size of the grids also varies. Simply put, when the size of the grid is suffi-

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*2 https://www.pixilart.com/

ciently large, we believe that the users perform the steering operations without difficulties, even if the grids are not displayed. However, the sufficient size is unknown. Moreover, in many applications including Microsoft Paint and Pixilart, users can use a magnifier that can enlarge the size of pixels (grids). For example, in Microsoft Paint, the size can be configured from one to eight pixels, and in Pixilart, from 36 to 216 pixels.

In this study, we conduct an experiment where participants fill various-size grids (Fig. 2b), and the grids are displayed or not depending on a condition. We also check whether the steering law holds even if the grids are not displayed. Based on the experimental results, we build design implications for grids. Our key contributions are as follows:

- We conducted an experiment where participants filled in the grids, with and without the grids being displayed. Although this task is one of the realistic steering tasks, the effects of grid visualization such as steering time and error rate have never been explored.
- Our results showed that regardless of the presence or absence of the grids, the observed movement times were similar. However, when the size of the grids was small (¡ 4.05–4.86 mm) and when the grids were not drawn, the error rate was higher. Designers can use the value of 4.05–4.86 mm as a standard threshold to determine whether the grids should be shown.

2. Related Work

2.1 Visual Feedback for Operations in GUIs

In Piccolo et al.'s experiment [9], participants conducted steering tasks without visual feedback, but were given audio, vibrotactile, or audio+vibrotactile feedback. Piccolo et al. found that the difference in accuracy for different feedbacks was not significant, but the task completion time for the vibrotactile feedback was longer. In a situation where the path is visible, users demonstrated better accuracy with the tactile and auditory+visual+tactile feedbacks [10]. However, the authors have not conducted comparative experiments under a condition when the visual feedback was absent or present.

Peephole pointing is a task where users acquire a target in a restricted view [11]. Cao et al. found that the movement time decreases with the increase of the restricted view. In the peephole pointing under other conditions, similar results have been observed by [12–14]. Filling the grids when the grids are not displayed can be considered similar to a task where users follow a path in a restricted view. As shown in Fig. 3, in such a situation, all parts of the path behind the cursor are visible; however, the visible part of the path in front of the cursor depends on the path width. Thus, based on the above studies, we presume that when the grids are not displayed, the movement time is slower.

Gutwin and Skopik conducted a steering experiment where participants draw paths by using various methods for magnifying certain parts of the path [15]. In a radar view, after participants move the cursor, the part of the path that was magnified also moves, i.e., participants conduct a steering task in a restricted view (see Figure 3 in [15]). Gutwin and Skopik found that in the radar view, magnification does not affect the movement time; even if the path ahead becomes smaller, the movement time does not change.

Also, in drive simulators [8] and video racing games [16], users follow a path in a restricted view where the condition of the path far away from the user is unclear. Bateman et al. [16] found that the movement time depends on the point of view but not on the amount of the visible path in front of the car.

Kulikov et al. compared constrained and unconstrained paths [17]. In their study, following an unconstrained path is a task where participants perform a crossing operation for two goals. However, Kulikov et al. did not consider the condition of the boundary lines of the path in steering operations being displayed or not.

In summary, existing studies showed that the performance of operations in GUIs depends on the view size and the visual conditions. In the grid-filling tasks, we believe that the presence of grids affects the performance because the grids change the appearance of the path.

2.2 Model for Steering Operation

The movement time (MT) of steering operations can be predicted by the steering law [1]. The global model of the steering law proposed by Accot and Zhai [1] is as follows:

$$MT = a + b \int_C \frac{dx}{W(x)} \qquad (1)$$

where C is the path shape, $W(x)$ is the path width in the cursor position (x), and a and b are regression constants (a and b). The integral term is the index of difficulty (ID) of the steering operation. For straight-line paths, the model can be expressed as follows:

$$MT = a + b\frac{A}{W} \qquad (2)$$

where A is the path length and W is the path width. ID is A/W. The steering law can be applied to various path shapes and input devices. Even in situations where users cannot grasp the path far ahead such as in driving, the steering law still holds [8]. Therefore, we believe that the steering law can also be applied to the grid-filling tasks.

Accot and Zhai have proposed a model of the average speed (v) for steering operations as follows:

$$v = a + bW \qquad (3)$$

Regarding the speed model, when the tolerance width which expresses the movement range of a cursor is unclear, the model is modified. For example, in driving, the tolerance width, which is a difference between the path width and the vehicle width (W_v), is not clear for drivers and thus, the average speed model can be modified as follows [18]:

$$v = a + b(W - kW_v) \qquad (4)$$

where k is an additional constant.

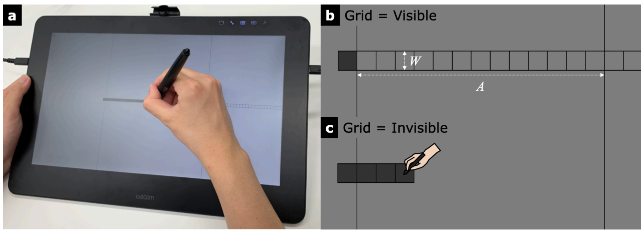

Fig. 2 (a) Apparatus. (b) Steering task with visible grid. (c) Steering task with invisible grid.

3. Experiment

3.1 Apparatus

We used an Apple MacBook Pro laptop (Intel Core i5, 2.4 GHz, two cores, Intel Iris 1536 MB, 8 GB of RAM, macOS Sierra). The input device and the display consisted of a Wacom Cintiq Pro 16 TDTH-1620/AK0 (15.6 in., 345.4 × 194.3 mm, 2,560 × 1,440 pixels, Fig. 2a). The full-screen experimental system was developed with JavaScript and allowed participants to interact with the screen through touch inputs by using a stylus (the screen did not register finger touching).

3.2 Participants

Twelve (nine male and three female) paid volunteers participated in the study (age: $M = 21.83$, $SD = 1.52$ years). All participants were right-handed and operated the stylus accordingly. Each participant received an equivalent of 23 USD for their time.

3.3 Task

Figs. 2b and c show the outline of our task. Participants touched a black square in front of a start line with the stylus and then crossed the start line. After crossing, the trial started, measurements began, and a start sound was played. The grid was filled in black color depending on the position of the participants' cursor (Fig. 3). Participants had to fill all grids in black from the start line to the end line. If the participant did not deviate from the grids and raised the stylus only after crossing the end line, a success sound was played. When the participant deviated from the grids before raising the stylus, a failure sound was played, and the trial was flagged as an error. If the participants failed, they redid the trial. We instructed all participants to move quickly, as long as they do not deviate from the path. In the case of Fig. 2c where the grids are not drawn, participants must not deviate from the invisible grids, and the grids are filled in black depending on the position of the cursor. In both conditions (Figs. 2b and c), because the initial black square was displayed, participants could presume the path width. In accordance with the existing steering studies [2,3], if the participant raised the stylus before the end line, the failure sound was played but no error was recorded.

3.4 Design, Procedure, and Measurements

The distance (A) from the start line to the end line was 720 or 1080 pixels (97.13 or 145.70 mm, respectively). The grid size (W) was 18, 24, 30, 36, or 40 pixels (2.43, 3.24, 4.05, 4.86, or 5.40 mm, respectively). To compare the effects of the grid, we tested under two conditions: with and without grids. When $Grid = Visible$, the grid was drawn in the path (Fig. 2b) and when $Grid = Invisible$, it was not drawn (Fig. 2c).

One *set* consisted of $2A \times 5W = 10$ trials for a fixed $Grid$ condition. The orders of A and W were randomized in a set. For each $Grid$, after an introductory practice set, each participant completed ten sets to produce experimental data. The order of $Grid$ was balanced among 12 participants. A total of 2,400 trials (i.e., $2Grid \times 2A \times 5W \times 10$ sets $\times 12$ participants) were conducted, which required approximately 20 min per participant.

The dependent variables included the movement time MT (the time from when the cursor crossed the start line to the time it crossed the end line, excluding error trials) and the error rate.

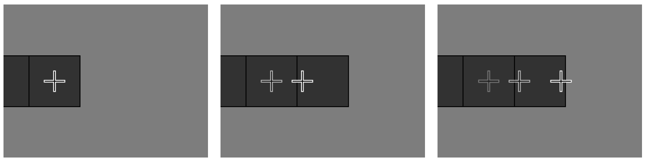

Fig. 3 When the crosshair cursor enters a grid, the grid is filled in black color.

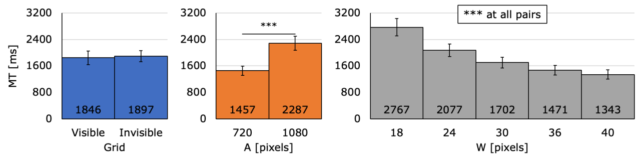

Fig. 4 $Grid$, A, and W vs. MT.

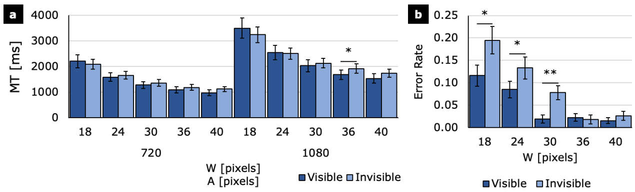

Fig. 5 (a) MT for $Grid \times A \times W$. (b) Error rate for $Grid \times W$.

4. Results

During 2,618 trials, 218 errors occurred (8.33%). We analyzed the data by using repeated-measures analysis of variations (ANOVA) with Bonferroni correction as the p-value adjustment method. The independent variables were $Grid$, A, and W. In our graphs of the results, the error bars represent the standard error, and ***, **, and * indicate $p < 0.001$, $p < 0.01$, and $p < 0.05$, respectively.

4.1 Movement Time

We observed the main effects for A ($F_{1,11} = 100.55, p < 0.001, \eta_p^2 = 0.90$) and W ($F_{4,44} = 81.44, p < 0.001, \eta_p^2 = 0.88$) but not $Grid$ ($F_{1,11} = 0.17, p = 0.69, \eta_p^2 = 0.015$). Fig. 4 shows the results of the post-hoc test. We also ob-

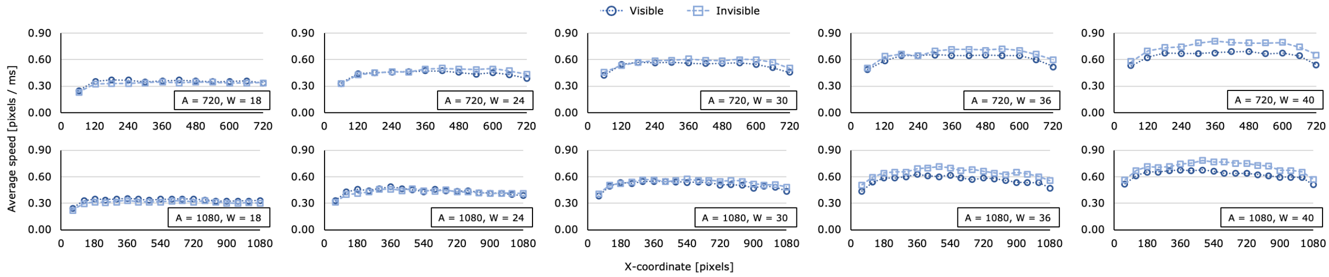

Fig. 6 Average speed every 60 pixels vs. x-coordinate of cursor for each condition.

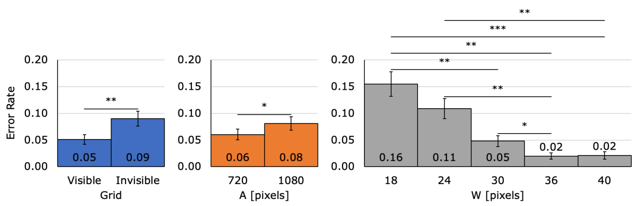

Fig. 7 *Grid*, *A*, and *W* vs. error rate.

served the interactions for $Grid \times W$ ($F_{4,44} = 3.55, p < 0.05, \eta_p^2 = 0.24$), $A \times W$ ($F_{4,44} = 32.22, p < 0.001, \eta_p^2 = 0.75$), and $Grid \times A \times W$ ($F_{4,44} = 4.67, p < 0.01, \eta_p^2 = 0.30$). When A increased, the difference between W values increased as well, which was consistent with the steering law: the movement time of steering operations depends on the ratio of the amplitude and width. For $Grid \times A \times W$, there were no significant differences between $Grid$ values (Fig. 5a).

We also plotted the average speed every 60 pixels for each condition in successful trials only (Fig. 6). The change of speed for each $Grid$ was the same, and the tendency of the speed was consistent with that of MT.

4.2 Error Rate

We observed the main effects for $Grid$ ($F_{1,11} = 12.11, p < 0.01, \eta_p^2 = 0.52$), A ($F_{1,11} = 4.92, p < 0.05, \eta_p^2 = 0.31$), and W ($F_{4,44} = 27.15, p < 0.001, \eta_p^2 = 0.71$). Fig. 7 shows the results of the post-hoc test. We also observed the interactions for $Grid \times W$ ($F_{4,44} = 3.55, p < 0.05, \eta_p^2 = 0.24$) and $A \times W$ ($F_{4,44} = 2.83, p < 0.05, \eta_p^2 = 0.20$). For $Grid \times W$, when W was small, the differences between $Grid$ values were significant (Fig. 5b).

4.3 Model Fitting

We verified the model fitness of the steering law (Equation 2) for each $Grid$. As shown in Fig. 8, in both $Grid$ conditions, the steering law showed good fits; we found that for predicting the movement time of the grid-filling task, the steering law does not have to be modified regardless of the presence or absence of the grids.

5. Discussions

For each condition, regarding MT, the difference between $Grid$ values hardly existed (Fig. 5a). However, when W was smaller than 36 pixels (4.86 mm), the error rate for $Grid = Invisible$ was significantly higher. We hypothesized that when the size of grids is sufficiently large, users are not

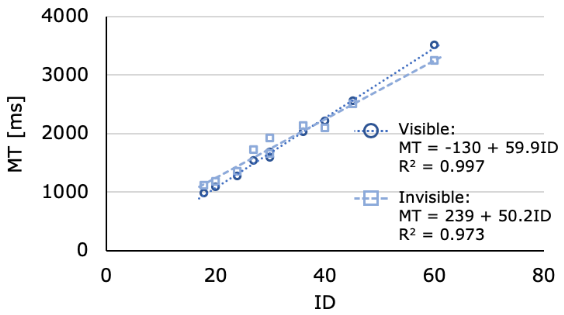

Fig. 8 *ID* vs. *MT* for each *Grid*.

frustrated when performing the grid-filling task. Based on our results, the hypothesis was accepted.

In Super Mario Maker 2, grids of approximately 6 mm are drawn on the screen of the Switch for making the course. As the size of these grids is larger than 4.86 mm, we believe that users can show good movement time and low error rate, even if the grids are not drawn. The grid size in Pixilart varies in the range from 36 to 216 pixels; therefore, on a PC with the same resolution as the one used in our experiment, users can forgo the grids if they dislike them. In contrast, Microsoft Paint has smaller grids (1–8 pixels); therefore, we recommend that the software has an option for users to choose whether the grids are displayed or not or has larger grids. In summary, we believe that designers do not need the grids to be displayed when the size of the grids is over 4.05–4.86 mm.

We also found that the steering law showed good fits regardless of the presence or absence of grids. These findings indicate that designers can configure applications such as picture drawing in pixel art based on a model. In addition, in pixel art, when users fill undesired pixels in a wrong color, they can modify the picture by setting the correct color and clicking on undesired pixels (Fig. 9). Thus, we believe that the movement time, including time for modifying the undesired pixels, can be predicted by a steering model combined with a pointing model such as Fitts' law [19, 20]. In summary, because the steering law holds in the grid-filling task, we believe that the difficulty of drawing a picture in pixel art can be defined and its movement time can be predicted. When users want to practice pixel art, the difficulty of a sample picture can be defined. We understand, however, that time is not the only important factor in a picture drawing task; the steering law is just one of the difficulty indicators.

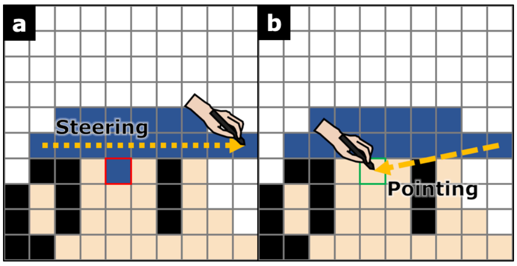

Fig. 9 (a) Filling one pixel in a wrong color while drawing a blue line. (b) Modifying the wrong color by clicking on it.

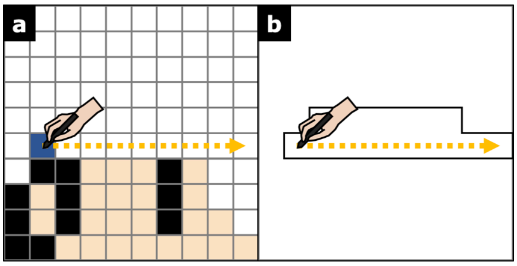

Fig. 10 (a) Deviating from the path upward when drawing a blue line. (b) Simplifying situation as a steering task.

6. Limitations and Future Work

In our experiment, we only tested drawing with a stylus; therefore, it is unclear whether our results can be applied to other input devices (e.g., finger). In the pointing operation, using a larger nib is known to increase the error rate [21]; hence, different results can be obtained if the grid-filling tasks are conducted by the other devices. Another limitation is that we tested only a straight-line path, although in many existing studies (e.g., [2, 5, 22]) non-linear paths have also been verified. We understand that testing non-linear paths is important because users sometimes fill in the grids on the paths. However, we cannot convert a grid-filling task into a non-linear path task because drawing a circle in pixel art without grids is too difficult or even impossible. Thus, our results do not show the effect of grids on any path shapes other than a straight line.

When users draw a blue line (Fig. 10a) for completing a picture (Fig. 1b), they can deviate from the path upward because the color above the line is the same as that of the line. That is, the users do not need to undo or correct the color in the deviated grids because the same color is used, even if they deviate from the path upward. In the experiment, although the path is simplified as a straight-line path, the actual path is such as in Fig. 10b. Yamanaka et al. modeled a situation where users follow a path made of segments with different widths, and the model is based on the steering law [23]. We found that the movement time of the grid-filling task can be predicted by the steering law, even if the task is such as in Fig. 10.

7. Conclusion

Based on picture drawing in pixel art applications, we conducted experiments where users fill various-size grids under a condition of whether the grids are displayed or not. Our experimental results showed that the movement time is not significantly affected by the presence of absence of grids. However, when the size of the grids is small (¡ 4.05–4.86 mm) and the grids are not displayed, the error rate is higher. In addition, a grid-filling task can be considered as a steering task, and we found that the steering law holds even if the grids are not displayed. Other operations in the grid-filling task can be considered as modeled operations (e.g., pointing and steering through sequential linear path segments). Thus, we believe that defining the difficulty of the grid-filling task in other shapes is possible by using the existing models.

We found an unexplored and realistic steering situation. We hope that this study and future studies based on this study will contribute to predicting the movement time in situations when the path width is not clear, such as picture drawing without grids in pixel art.

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