Modeling Drone Pointing Movement with Fitts' Law

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ABSTRACT

Although numerous studies have focused on interfaces for maneuvering drones, a method for evaluating these interfaces has not been established. A pointing experiment was carried out with a drone in this study. The results indicate that the target distance and target width affect the movement time and error rate while maneuvering. This is consistent with the results of previous pointing studies. Fitts' law was not a good fit ($R^2 = 0.672$), while the data fit well to a two-part model ($R^2 = 0.993$). Based on these results, we propose future experimental work that could contribute to improving drone interfaces.

CCS CONCEPTS

- **Human-centered computing → Pointing**.

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KEYWORDS

Drone; pointing task; Fitts' law; Human-Drone Interaction.

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INTRODUCTION

Numerous studies have focused on interfaces for maneuvering drones[8–10], however, a method for evaluating these interfaces has not been established. The factors affecting the movement time and error rate of a drone while maneuvering are still unknown.

Fitts' law[6] and the steering law[1] are used to evaluate graphical user interfaces (GUIs)[5] or are used as a guideline for interface design. For example, pointing operations in GUIs involve the selection of a target (Figure 1), and the movement time (MT) can be predicted with high accuracy using Fitts' law (Equation 1)[6]. In addition, as shown in Equation 1, the movement time can be decreased by decreasing the distance to the target (D) or increasing the target width (W). a and b are regression constants (hereafter, a, b, and k are also used as regression constants). As mentioned above, modeling an operation is considered an important design guideline for drone interfaces.

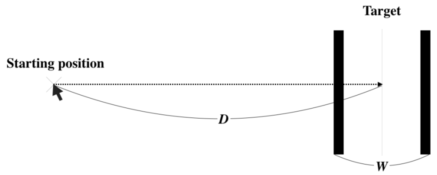

Figure 1: Pointing in GUIs

$$MT = a + b\log_2\left(\frac{D}{W} + 1\right) \tag{1}$$

The pointing operation is also involved in drone movement, e.g., directing a drone to land on a desk[1] (Figure 2 upper). In this scenario, the drone must land on a desk with a certain width and at a certain distance. The factors involved in this scenario are similar to the factors in pointing operations in GUIs, which are target width (W) and target distance (D) (Figure 1). Using a drone to take a self-portrait may also be considered a pointing operation (Figure 2 lower). In this scenario, the drone must be flown to a certain distance and the subject must be brought into its field of view. This operation is also similar to the pointing operations in GUIs. Therefore, we conducted a pointing experiment with a drone in this study. By our experiment, the effect of the pointing factor on a maneuvering drone was investigated and the drone's pointing motion was modeled. We believe that our results will contribute to creating better drone maneuvering guidelines and interface design.

Figure 2: Example of pointing in with a drone (upper: landing on a desk; lower: self-portrait taken by the drone).

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[1] https://www.tethertools.com/product/aero-launchpad/

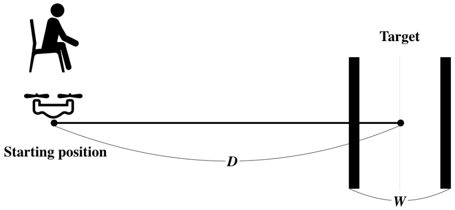

Figure 3: Experimental outline

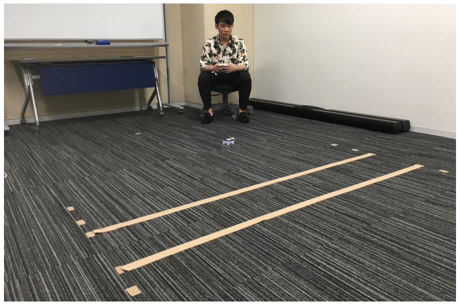

Figure 4: A photograph of the actual experiment.

Figure 5: Drone and controller used for experiment

EXPERIMENT

Task

Participants were required to control a drone to take off from an initial area and land it within the target width, indicated by 2.0 m tapes(Figure 3). This task is simulated in the upper panel of Figure 2. The target width included the width of the tapes. To reduce the effect of the difference in height of each participant, participants were asked to sit on a chair at a distance of 1.0 m from the initial area (Figure 4). The participants were requested to perform the task as quickly and accurately as possible. In this experiment, if the drone landed and stopped with its center within the target width, the trial was considered successful.

Apparatus

The experiment was conducted in a room (6.0 m in length, 2.5 m in width, 2.5 m in height) without any obstacles. The air conditioning in the room was turned off. A drone called "CCP programming tetral (60.0 mm in length, 60.0 mm in width, 36.0 mm in height)[2]" with a dedicated controller was used for the experiment (Figure 5). The speed of the drone was controlled with the controller's stick by moving it on two axes. The controller provided three different speeds settings, and the participants were required to conduct the task using the fastest speed.

Design and Procedure

The target width W was 0.4, 0.7, or 1.1 m, and the target distance D was either 2.0 or 4.0 m. The participants were given a time of approximately 10 minutes to familiarize themselves with the drone controls. Then, the participants conducted the task until they succeeded five times in each condition. Selecting from the six conditions ($2D \times 3W$), the participants performed the task three times as practice, and experimental data was obtained while the participants performed the task ten times. The participants repeated the above in all conditions. The order of selecting the conditions was counterbalanced by a Latin square. In total, 720 trials (i.e., $2D \times 3W \times 10 sets \times 12 participants$) were carried out, and the time required was approximately 50 min per participant.

Measurements

The movement time (time from takeoff to when the drone landed and stopped within the target width) and error rate were recorded. MT was measured from the videos of the experiments.

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[2] http://ccp-jp.com/toy/products/item/262/

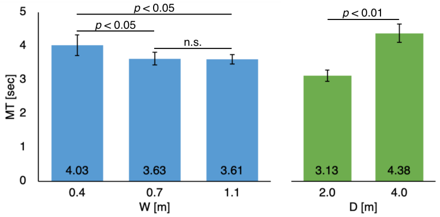

Figure 6: Effect of D and W on MT.

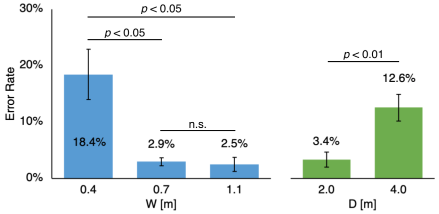

Figure 7: Effect of D and W on error rate.

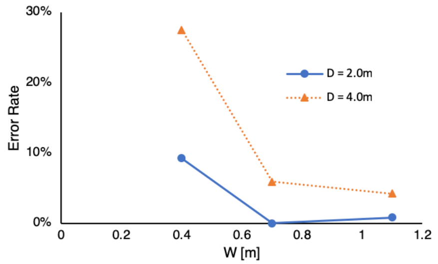

Figure 8: Error rate of $D \times W$.

RESULTS

The data were analyzed using repeated-measures ANOVA and the Bonferroni post hoc test. Error bars in the graph indicate standard error. Data from four trials were erased by mistake; hence, the data from only 716 trials were used as the experimental data. The number of errors was 57 (7.96 %).

Effect of D and W on MT

We observed the main effects for W ($F_{2,22} = 4.99$, $p < 0.05$) and D ($F_{1,11} = 62.07$, $p < 0.01$) on MT. As a result of multiple comparisons, it was observed that increasing the D ($p < 0.01$) and/or decreasing W ($p > 0.10$ between $W = 0.7$ m and $W = 1.1$ m, the others were $p < 0.05$) increased the MT (Figure 6). The interaction in $D \times W$ on MT was not determined.

Effect of D and W on Error Rate

We observed the main effects for W ($F_{2,22} = 10.07$, $p < 0.01$) and D ($F_{1,11} = 16.49$, $p < 0.01$) on the error rate. As a result of multiple comparisons, it was observed that increasing D ($p < 0.01$) and/or decreasing ($p > 0.10$ between $W = 0.7$ m and $W = 1.1$ m, the others were $p < 0.05$) increased the error rate (Figure 7). The interaction in $D \times W$ was found ($F_{2,22} = 5.85$, $p < 0.01$). We found that increasing the D increased the effect of W (Figure 8).

Model fitness

In the case of movement time, we found that MT is strongly affected by D and W, and thus, we verified whether Fitts' law is suitable for our results (Equation 1). The relationship between MT and ID is shown in Figure 9. Considering the typical threshold ($R^2 > 0.90$[12][7]), Fitts' law was not well-suitable ($R^2 = 0.672$).

As shown in Figures 11 and 12, changes in D and W did not cross. In this case, Shoemaker et al. reported that the two-part model (Equation 2, where the logarithm is ID_k) is more suitable than Fitts' law[11], thus we decided to verify the suitability of the two-part model.

$$MT = a + b \log_2 \left(\frac{D + W}{W^k} \right) \tag{2}$$

Fitts' law only contains two constants, whereas the two-part model contains three constants. Therefore, in addition to R^2, we analyzed the suitability using the Akaike information criterion (AIC)[3]. A model that has lower AIC and higher R^2 is considered a good model. In addition, if the difference between the AIC values is more than 10, the difference is statistically significant[4].

From Table 1, one can see that the two-part model is more suitable (Figure 10). The speed of the drone was slow in the experiment, although we used the fastest speed and the difference between D

values was large. Therefore, we believe that the middle of the pointing movement is only affected by D. Therefore, experiment produced the results shown in Figures 11 and 12, and that the two-part model demonstrated good suitability.

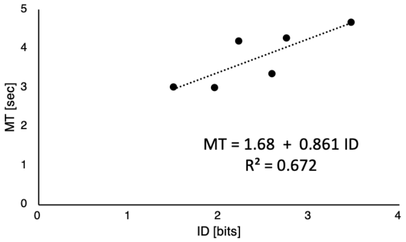

Figure 9: Model fitness for Fitts’ law.

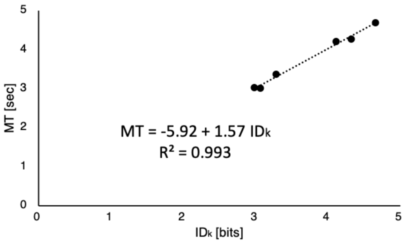

Figure 10: Model fitness for the two-part model.

Table 1: Comparison of the two models.

Eq.	*a*	*b*	*k*	R^2	*AIC*
1	1.68	0.861		0.672	13.3
2	-5.92	1.57	0.384	0.993	-7.34

DISCUSSIONS AND LIMITATIONS

Several participants indicated that it was difficult to determine the distance between the drone and the target when the distance was large (i.e., $D = 4.0$). Furthermore, a few participants indicated that the drone did not actually land on the target in several instances when the target width was the smallest (i.e., $W = 0.4$), although the drone seemingly flew over the target and landed successfully. Based on the above comments, it is clear that the participants underestimated the target width to be small when the distance was high (i.e., the target was far away). This result is consistent with the fact that the error rate is large (17.9%) and the error rate increases with increasing distance (Figure 8) when $W = 0.4$. We believe that if a drone with first-person view (FPV) is used, the participants can accurately grasp the target width, even if the distance is large; the results from using a drone with FPV will differ from those presented here.

In this experiment, a drone with relatively lower speed was used, thus the drone’ s movement was only affected by D during a portion of the operation. Therefore, if a drone with higher speed is used, the two-part model and Fitts’ law might show good suitability. Thus, we believe that a drone with third-person view (TPV) can be modeled using the two-part model or Fitts’ law.

In this experiment, the location of the participants was close to the start area (Figure 4). In addition, some scenarios exist, such as, when the location of a participant is close to the target (i.e., a drone heads towards participants) and when the location is the midpoint between the start area and the target. The results of this experiment show that it is difficult to grasp the distance between the drone and the target when the distance is large. We believe that this difficulty is due to the standing position, thus, different standing positions may produce different results. Therefore, the results for a given W value are nearly unchanged at large or short distances. Therefore, we will conduct future experiments where participants standing in different positions. In addition, drones are maneuvered in a room and outdoors (Figure 2 upper). Therefore, we should investigate the effect of wind.

We could model the pointing operation of the drone by our results. Crossing and steering operations are present in drone operations. Crossing is to pass the frame and door in a drone race[3], and steering is to fly a drone through a corridor[4] (Figure 13). In GUIs, the pointing operation[5], crossing, and steering[1, 2] can be modeled with many devices, such as mice and trackpads. Because we could model the pointing operation of a drone, we believe that the crossing and steering operations can also be modeled. If all these operations can be modeled, a theoretical index for evaluating drone interfaces can be developed.

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[3] https://youtu.be/FgKZLk7pYrY

[4] https://youtu.be/MI2tgUKK3Ds

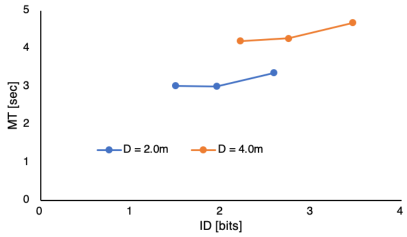

Figure 11: Relationship between ID and MT divided for each D value (Fitts’ law).

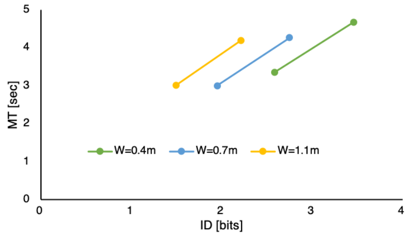

Figure 12: Relationship between ID and MT divided for each W value (Fitts’ law).

Figure 13: Example of crossing (drone race) and steering (fly a drone through a corridor).

CONCLUSION

As a result of the pointing experiment with a drone, it was found that the movement time (MT) and error rate were affected by the target distance (D) and target width (W). The speed of the drone was slow and the difference between the two D values was large, thus there was a section of the operation where D was independently influenced. As a result of verifying the model suitability, Fitts’ law did not show a good suitability ($R^2 = 0.672$), while a two-part model showed good suitability ($R^2 = 0.993$). Furthermore, we showed that research on GUIs can also be used for drone interface research. Based on the results of this experiment, we proposed future experimental research that may contribute to improving drone interfaces.

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