Targeted Steering Motions

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Abstract
In this paper we investigate targeted steering motions. Fitts' law is a very successful model to explain human targeting behavior, while the Steering law has been used to model steering motions. Dennerlein et al. combined these two models to explain targeted steering motions, but this combination introduces additional parameters. In this paper, we present a new, simpler, model that can be used to predict targeted steering motions.

Keywords
Targeted Steering motion, Fitts' law, steering motions.

ACM Classification Keywords
H.1.2 User/Machine Systems: Human factors, Human information processing

Introduction
Targeted steering is a common task while interacting with a computer. We define it as a constrained motion (such as through a tunnel) with a limited target area where the motion has to come to a stop. In this paper we investigate only straight tunnels with a target at the end of the tunnel, such as in Figure 1.

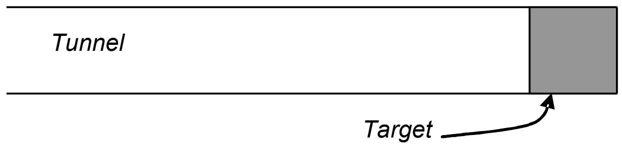

Figure 1: Tunnel with a target

Examples of targeted steering tasks include menu selection, scroll bar interactions, as well as several kinds of selection techniques in graphical user interfaces. Although in some cases the Steering law or the Fitts' law may be sufficient for modeling these tasks, there are cases where this does not hold.

In 2000, Dennerlein et al. [2] introduced a model for the task shown in Figure 1. This model was a byproduct of research that the authors were doing on steering with force-feedback and is the first attempt to model targeted steering behaviors. The authors hypothesized that the "difficulty of a combined steering and targeting task would depend in equal parts upon the difficulty of the steering and targeting components to the task" and proposed the following model [2]:

$$MT = a + b \cdot ID_S + c \cdot ID_T$$

where MT is the movement time, ID_S is the index of difficulty of the steering task, and ID_T is the index of difficulty of the targeting task, while *a*, *b* and *c* are empirically determined constants.

Their experiments showed that the steering term ID_S was much more dominant as it was highly correlated (r^2 = .98) with the movement times, while the correlation of the targeted term IDT, which corresponds to a Fitts' task, with time was low (r^2 = .52).

Base Models

In this section we briefly describe the Fitts' and Steering models.

Fitts' Law

Fitts' law [3] has been frequently used and studied extensively [5] in the field of HCI. The model is usually used in the following form:

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

The model predicts the movement time for a particular target based on the *ID* of the task, which is determined by the width of the target (*W*) as well as the distance to the target from the origin (*A*), while *a* and *b* are empirically determined constants. The logarithmic part of Fitts' law is also known as the Index of Difficulty (*ID*) of the task.

Steering Law

Accot and Zhai introduced the steering law [1] to predict movement time through a particular space with constraints, such as a straight or a narrowing tunnel. The time to steer through a straight tunnel with width *W* and length *A* is given by the following equation:

$$MT = a + b\left(\frac{A}{W}\right)$$

where *a* and *b* are empirically defined constants and the A/W term is the Index of Difficulty (ID) of the task. The authors also provided a more general equation for

ID that covers curvilinear tunnels, however we only discuss straight tunnels in this paper.

Modeling

Although the model presented by Dennerlein et al. explains targeted steering extremely well (r^2=.98), the equation has three parameters (two independent variables). This is cumbersome, as it requires that any user of the model fit his/her data to three parameters. Furthermore, the Dennerlein Model contains a second independent variable in the equation, which means that the correlation will always be higher regardless of circumstances because the model has an extra degree of freedom (see e.g. [6]). Finally, it is unclear if there are not multiple sets of parameters that work equally well – which would prevent users from comparing models against each other.

In this paper, we propose a targeted steering model that is simpler than Dennerlein et al.'s model as it uses only two parameters. By combining the two indeces of difficulty (the steering and targeting ID) into one variable, we eliminate one parameter and create a simple linear equation in line with the Fitts' and the Steering law models.

Hypothesis: The following equation provides a good fit for a motion through a straight tunnel with a target at the end (targeted steering motion):

$$MT = a + b \times (ID_S + ID_T)$$

where *MT* is the average movement time, a and b are empirically determined constants. ID_S is the index of difficulty of the steering subtask (modeled by the Steering law) and ID_T is the index of difficulty of the pointing subtask (modeled by Fitts' law).

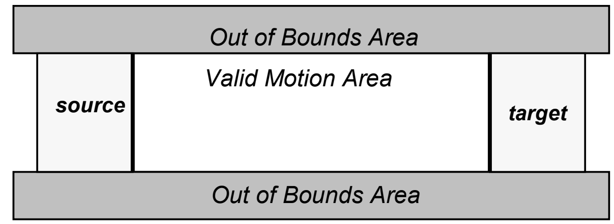

Figure 2: Diagram of the layout of the experiment

User Study

Our user study was performed on a P4-2GHz computer running Windows XP. The participants used a pen to perform the necessary input on a digitized Wacom 1024x768 LCD tablet. The software was written using Java version 1.5.0. Twelve paid volunteer participants (5 male, 7 female, 2 left-handed) were recruited from a local university campus. Participants ranged in age from 19 years to 35 years (mean = 26, sd = 5.33). The participants were randomly assigned to two groups (Group 1 and Group 2, each 6 people) to counterbalance learning/tiredness effects.

Method

The task contained five factors: the tunnel length *A*, tunnel width *Wv*, source/target horizontal width *Wh*, movement direction *D*, and constraints *C*. *A* varied among 3 levels: 31, 63 and 255 pixels; *Wv* varied among 3 levels: 63, 31, and 15 pixels; *Wh* also varied among 3 levels: 127, 63, and 15 pixels. There were four conditions for *D*: Left, Right, Up and Down motion direction; and two conditions for constraints *C*: with and without. Direction *D* was randomly assigned to each condition. Each participant performed 6 successful trials for each combination, thus making 324 strokes in total (excluding erroneous strokes). A diagram illustrating the task is shown in Figure 2.

The participants were asked to make a stroke from the ‘source’ area (blue on the screen) to the 'target' area (green). The motion was to take place in the ‘valid motion’ area (white). In the with constraints condition, if the participant touched the ‘out of bounds’ area (pink), he/she had to repeat the trial.

In the without constraints condition, the participants did not have to restart the trial, unless they failed to reach the target area. In this condition, the participants were instructed as follows: “You are required to stay within the ‘valid motion’ area, however unlike the with condition, if you touch the border, you will be allowed to continue, that is you won’t have to restart the trial”. We included this condition, as we wanted to analyze the effect of the visual tunnel on the motion. The participants in Group 1 performed the with constraints tasks first, while the participants in Group 2 performed the without constraints tasks first.

Results

Three measurements were taken. The first measurement was the time *T* elapsed (in ms) between the moment that the pen touched the screen and the moment that it was lifted again. The second measurement was the number of errors *E* that the user committed. We used the Out of Path Movement (OPM), measure proposed by Kulikov et al., [4] to describe sampled points in the *out of bounds* area in comparison with the total amounts of sampled points while performing the task. The proposed *ID* values vs the time taken to perform the stroke are shown in figure 3.

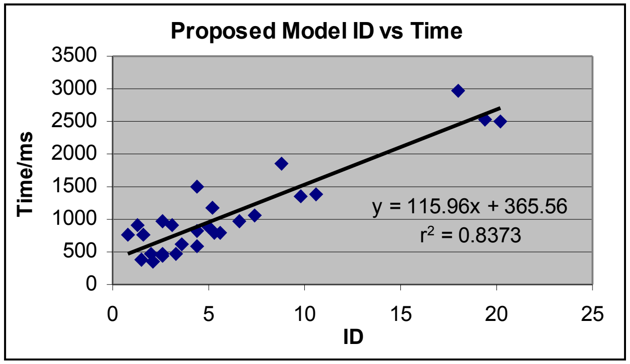

Figure 3: Linear regression of ID values of the proposed target steering model and Time (for with constraints condition)

Model	***Dennerlein et al Model***	***Target Steering***	***Steering Law***
r^2 with constraints	.945	.837	.702
r^2 without constraints	.933	.799	.661

Table 1: r^2 values for the two conditions: with and without constraints for the 3 models that we are comparing.

The main effect for the group that the participants were assigned to was not significant[1], that is, the order in which the participants performed the task did not have a significant effect on the outcome of the experiment. The main effect for direction was significant. This follows Dennerlein et al.’s findings that the vertical movements took longer than horizontal ones. To generalize the results, we will use the average times of

[1] Due to space constraints we do not list all Fisher-test values that back our claims.

the four directions that we tested from here on. We also average the times across the different trials that the participants performed (6 trials per condition), as well as across the 12 participants. With that each time *T*, error *E*, and OPM *L* value listed below is averaged across 72 data points.

Correlations
For both constraint conditions, the r^2 values are listed in table 1 for the following three models: The Dennerlein et al.'s model, the proposed Target Steering Model, and the Steering law model. Dennerlein et al.'s model had the highest correlation with the data (r^2 =.945), followed by our target steering model (r^2 =.837). The Steering law had only a correlation of r^2 =.702 with the data. For the *without* constraints condition, the same ordering can be observed and the values are comparable to the *with* constraints condition.

Errors and OPM
We considered a trial to be erroneous if one of the following occurred: In the *with* constraints condition, the participant pressed the stylus outside the source area, released the stylus outside the target area, or touched the out of bounds area. In the *without* constraints condition, the participant pressed the stylus outside the source area, or released it outside the target area. In this condition, if the participant moved within the out of bounds we did not consider this an error but collected data for the out of path movement (OPM) measure described earlier.

On average, in the *with* constrains condition, the participants made 27.9 errors during the 162 trials that they had to perform (17.2 %). The lowest error count was 6, while the highest was 134. This high value is somewhat extreme. The reasons for this is that the respective participant was using a tablet for the first time and had initially quite a difficult time aiming when the *Wv* and the *Wh* values were small (15 pixels). However, during the experiment, the participant got accustomed to the tablet and apart from the initial errors, the overall timing results were comparable to other participants, therefore we do not count this participant as an outlier.

In the without constraints condition, the participants averaged 13.4 errors during the 162 trials that they performed (8.3%). The total average OPM was very low: 0.84%. That is only 0.84% of the participants' motion was in the out of bounds areas.

Discussion
We used our results to compared three models: Dennerlein et al. model, the Steering law[2], and the proposed target steering model. Although Dennerlein et al.'s model provides a considerably better fit for the data, it has an extra independent variable compared to all other models. As discussed above, the addition of an extra parameter will always improve the correlation of the model with any data. Hence, having a model with fewer parameters is clearly desirable. Thus we claim that our target steering model is a good alternative choice to explain targeted steering motions, as the correlations for our new model are reasonably good. It also has the advantage of being a simpler model and can be visualized by a 2D straight-line graph.

[2] Amplitude *A* in the Steering law included the length of the tunnel as well as half of the source area and half of the target area to account for the fact that some motion occurs in those areas. Most of the participants did utilize about half of these areas.

The very low OPM value (0.84%) indicates that although technically the participants were allowed to move in the out of bounds areas, most of the motion still took place inside the tunnel that they were supposed to move through. When the Steering law was developed, which is similar to our with constraints condition, the authors used an experiment where the participants had to redo the trial if they touched a tunnel border. The results from our without constrains experiment give basis for conclusion that once users are given motion constraints, they are likely to stay within them. Although the overall OPM value (0.84%) represents the average across all of tunnel widths, the average OPM for the smallest tunnel width (15 pixels) was also relatively low: 2.46%. This is well below the 4% average error rate that is "expected" in Fitts' law experiments [5].

The two indices of difficulty (Fitts' and Steering) that we combine in this paper are quite different as they have different units and represent different motions. However we hope that our work provides further insight into targeted steering motions, a topic that has not been investigated much.

Conclusion

In this paper we proposed a new model for targeted steering motions. We conducted a user study and the analysis shows that the new Target Steering model has a very good correlation with the data. Although the model proposed by Dennerlein et al. has a higher correlation with the data, it has an extra free variable, thus that model will always have a higher correlation under any circumstances.

The proposed Target Steering model is simple as it has only one independent variable. It also combines the indices of difficulty from Fitts' law and the Steering law into one, thus basing itself on proven and accepted models.

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