Measuring the Effective Parameters of Steering Motions

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ABSTRACT

The steering law model describes pointing device motion through constrained paths. Previous uses of the model are deficient because they are built using only error-free responses, ignoring altogether the path of the cursor. We correct this by proposing and validating a technique to include spatial variability, including errors. The technique is a variant of the well-known "effective target width" used in Fitts' law models. An experiment designed to test our technique demonstrates the improvement: Correlations are consistently higher when spatial variability is included in building the model. Suggestions to aid further development of the steering law model are included.

Author Keywords

Steering law, effective width, error rate, Fitts' law

ACM Classification Keywords

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

INTRODUCTION

The Human-Computer Interaction (HCI) community is constantly seeking to develop formal models that are useful to either describe or predict human behaviour in interaction with technological artifacts, such as computer systems. Fitts' law [5] is an exemplary example (see [6] for a review). In 1997, Accot and Zhai [1] used Fitts' law to develop a model for path-following tasks. Path-following tasks are distinctly different from target acquisition tasks. Rather than moving to and selecting an object as quickly and accurately as possible, subjects manipulate a device – or an on-screen tracking symbol controlled by the device – along a path. Navigating hierarchical menus is an example. While expeditious movement remains the goal, users must attend to the entire movement, rather than to the final selection only. Accot and Zhai called the model "the steering law".

STEERING LAW

The steering law predicts the movement time through a particular space with constraints, such as a straight or a narrowing tunnel. Figure 1 shows a tunnel with side constraints, and a path that the cursor might follow in getting from one side to the other.

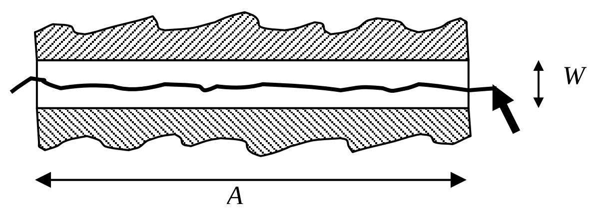


Figure 1: This movement through a tunnel constraint is modeled by the steering law [1]

The time to navigate through a straight tunnel with width *W* and length *A* is given by the following equation:

$$MT = a + b(ID) \tag{1}$$

where

$$ID = \frac{A}{W} \tag{2}$$

ID is the Index of Difficulty of the task shown in figure 1. Equation 2 applies only to straight tunnels. A more general equation for *ID* of any curvilinear tunnel is

$$ID = \int \frac{ds}{W(s)} \tag{3}$$

The integration variable s is the curvilinear abscissa and $W(s)$ for the tunnel width at s.

The steering law is a welcomed tool for HCI researchers and a number of studies have been conducted using the model [2, 3, 4]. These models are fairly new development and must undergo rigorous examination to be as successful as Fitts' law is for point-select tasks. In this paper we address several important aspects of the model.

Issues with Steering Law

One aspect of Fitts' law introduced after the original publication is the "effective target width". In calculating the index of difficulty, the term W_e, for the effective target width, is used in lieu of W. This term is calculated from the standard deviation of the end-point scatter data:

$$W_e = 4.133 \times \sigma \quad (4)$$

The steering law, however, does not account for errors. In [1], if the participants committed an error, the trial was rendered invalid. We feel this is limitation in the steering law, as variability and fallibility in human responses are ubiquitous in computing, as in life. The objective of the experiment described next is to correct this by introducing the effective width W_e into the steering law for straight tunnels.

METHOD

Participants

Sixteen volunteer participants (9 female, 7 male) were recruited from the local university campus via a distribution list and advertisement postings around campus. All were right-handed.

Apparatus

The study used a P4 2 GHz desktop computer. Output was viewed on a 1024 x 768 Wacom digitizing LCD tablet PL-400. Two input devices were used: an optical two-button mouse with a scrolling wheel, and a stylus on the Wacom tablet. Software was developed in Java 1.5.1.

Design

The experiment was a 2 x 2 x 2 x 5 x 5 mixed design. Group was a between-subjects factor with two levels (8 participants per group), with participants randomly assigned to Group 1 or Group 2. The within-subject factors were Constraint (None vs. Lines), Direction (Right vs. Left), Device (Mouse vs. Stylus), Amplitude (25, 50, 100, 200, 400 pixels) and Width (7, 15, 23, 31, 63). Figure 2 shows the layout of the areas that the participants saw. Part (a) shows the interface for Constraint = Lines, while (b) shows Constraint = None.

The participants in Group 1 first performed with a mouse, while those in Group 2 used a stylus first. Constraint and Direction were counterbalanced using a Latin square. Trials were randomly presented to the participants and each participant performed 9 strokes for each Amplitude/Width combination.

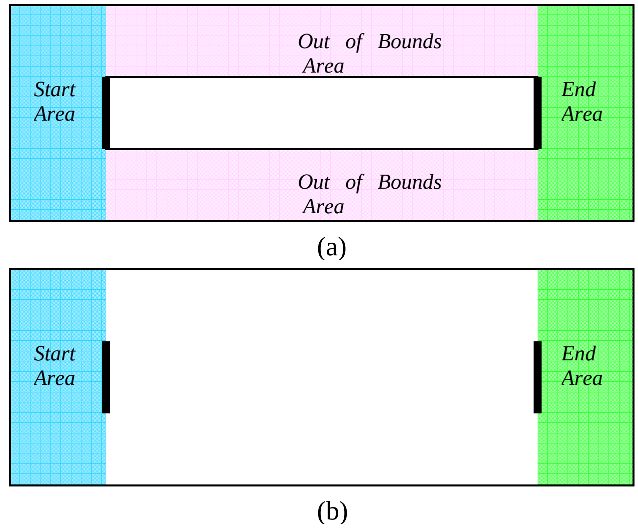


Figure 2: Layout of the interface used for the study, where Direction = Right: a) Constraint = Lines; b) Constraint = None

Procedure

The participants were first briefed on the experiment and the tasks. The purpose of the experiment, however, was only revealed at the end of the study, so that the participants would not be inclined to make wide (or narrow) strokes to skew the results. The task was to make a stroke from the starting area (on this screen this area was blue) to the finishing area (green), passing the starting and finishing lines. They were also told to try to avoid crossing the constraint lines and to avoid the out of bounds areas (pink) when these were present (see figure 2).

When using the stylus, the participants were allowed to place the Wacom tablet on their knees or on the desktop, which ever was more comfortable. However, when using the mouse, the tablet was placed upright on the desktop so the participants could see the output without any difficulties.

The participants were told to perform a stroke as quickly and as accurately as possible. Some participants asked which was more important, speed or accuracy. So as not to skew the results in any one particular direction, the response of the experimenter was "It is up to you".

Measurements

While the stroke was being made, the position of the cursor was sampled according to the system's speed (approximately 80 samples per second). The dependent variables were: Time (time taken to move the cursor from the start line to the end line), SD_y (Standard Deviation in the sampled y-data between the start line and the end line), and *OPM* (Out of Path Movement, percentage of sample points outside the Constraint lines). For example if 100 points were sampled and 14 of those points were outside the Constraint lines (in the 'Out of Bounds Area' in figure 2a), then *OPM* would be 14.

RESULTS AND DISCUSSION

We begin by analyzing the main effects on the measures of movement time, SD_y, and *OPM*.

Movement Time

The grand mean for movement time was 316.1 ms. The stylus was 40% faster than the mouse, with means of 262.9 ms and 369.2 ms, respectively. The difference was statistically significant ($F_{1,14} = 15.93$, $p < .005$). The left to right movement was 12% faster than right to left, with means of 297.8 ms and 334.4 ms, respectively. The difference was statistically significant ($F_{1,14} = 4.70$, $p < .05$). On average, the movement time for tunnels without side lines (Constraint = None) was 42% faster than for tunnels with side lines (Constraint = Lines). The mean times were 261.2 ms and 371.0 ms respectively; the difference was significant ($F_{1,14} = 45.20$, $p < .0001$).

Standard Deviation

The overall SD_y for the experiment was 4.164. When the participants used mouse, SD_y was 62% higher than stylus. The means were 5.125 and 3.167 respectively. The difference was statistically significant ($F_{1,14} = 110.53$, $p < .0001$). Main effect for Direction was not significant: $F_{1,14} = .87$, *ns*; the means were 4.119 for left to right motion and 4.173 right to left. SD_y was 11% higher for Constraint = None, with mean 4.360, than for Constraint = Lines, with mean 3.932. The difference was significant ($F_{1,14} = 16.64$, $p < .005$).

Standard deviation in the y-values (SD_y) is important in this user study and it was calculated from the sampled y-values. SD_y gives us an idea of how much of the tunnel was actually used in making a stroke. As in Fitts' law studies, giving constraints does not necessarily mean participants follow the constraints exactly. In steering through a very wide tunnel, only a fraction of the width may be used, however steering through a very narrow (long) tunnel, the tunnel side lines will probably be crossed. We feel these behaviors are an important part of path-following tasks and need to be included in the model.

Index of Difficulty

The correlation between Time and the index of difficulty (*ID*), as defined in equation 2, was .910 for mouse and .914 for stylus (see Table 1). However the correlation between Time and the effective index of difficulty (ID_e) was higher: .961 for mouse and .936 for stylus. The effective index of difficulty uses the W_e term (see equation 4). Only values sampled inside the tunnel (that is, between the start and end lines on the horizontal axis) were used.

That the correlations are higher using ID_e than using *ID* is a welcome outcome since it suggests that including spatial variability in steering law models not only improves the external validity of the model (because it models what participants actually do) but also produces a better model. Thus, the benefits in using W_e and ID_e in building Fitts' law models for pointing tasks also apply in using W_e and ID_e in building steering law models.

Figure 3 compares the actual width presented to the participants and the effective width for the stylus and mouse. Not surprisingly, as path width increases, participants do not use that the available width.

Model	Mouse	Stylus
ID vs. Time	$r = .910$	$r = .914$
ID_e vs. Time	$r = .961$	$r = .936$

Table 1: Correlation between Time and two forms of index of difficulty for the task, the *ID* and the ID_e

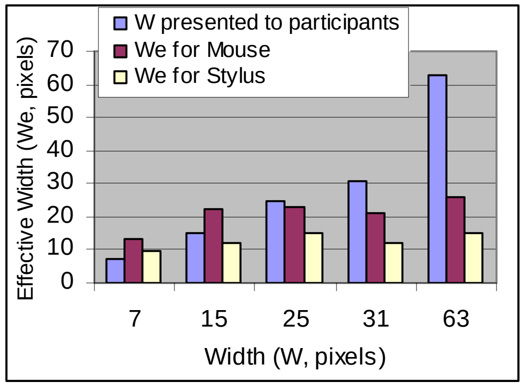


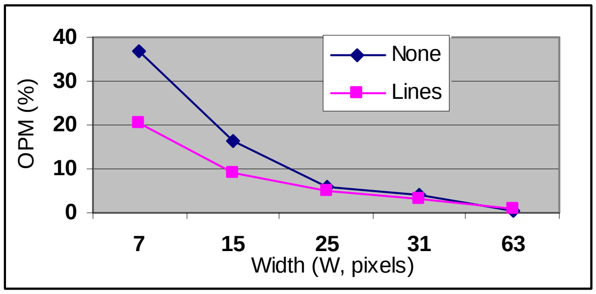
Figure 3: Comparison of W (pixels) against *We* for mouse and stylus

Out of Path Movement (*OPM*)

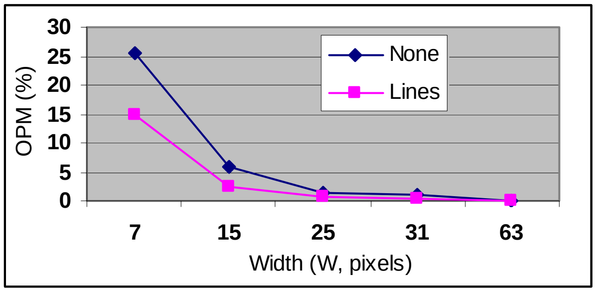
The overall mean for *OPM* was 7.690. *OPM* for mouse was 97% higher than for stylus! The *OPM* for mouse was 10.20 while for stylus 5.178; this difference is statistically significant ($F_{1,14} = 24.45$, $p < .0005$). *OPM* for left to right direction was 7.706, and 7.674 for right to left motion. As with SD_y the difference was not significant ($F_{1,14} = .01$, *ns*). *OPM* for Constraint = Lines was 5.700 while for Constraint = None was 9.681, or 70% higher. This difference was significant ($F_{1,14} = 89.99$, $p < .0001$).

Interesting is the fact that *OPM* was lower when Constraint = Lines than when Constraint = None. This shows that participants were more careful in carrying out the task when visible constraints were present.

From figure 4 we see that for smaller path widths, the *OPM* is quite high. In fact there were only a few conditions where *OPM* was 0, that is the participants went outside of the tunnel sides (or imaginary sides, when Constraints = None). However in the user study conducted in [1], the trials were discarded where the user went outside of the given tunnel. From our data we can see that in only 46 (out of 200) different combinations of conditions users committed no errors, which is 23%.



(a)



(b)

Figure 4: Comparison of W (pixels) against the *OPM* (%) for (a) Mouse, and (b) Stylus

Table 2 shows another important result. When Constraint = None, the average *OPM* is about 1.6 times higher for mouse and 1.75 times higher for stylus! When the steering law was first derived [1], an experiment similar to ours (Constraint = None) was used for crossing-based targeting motion (the only difference was the required error-free crossing). That motion was a targeting motion, and not a steering motion. As we can see, the users while making the stroke in the crossing-based targeting motion do not concern themselves much with the motion before the target. Therefore the original experiment that was used to derive the steering law does not fit the type of task that the steering law models, and this further reinforces the need to re-examine the steering law.

Constraint	Mouse	Stylus
Lines	7.426%	3.272%
None	12.22%	5.733%

Table 2: *OPM* when Constraint = Lines and when Constraint = None for mouse and stylus.

Device

All participants were regular mouse users, and most did not have any experience with the stylus. All participants spoke highly of the stylus after the experiment, preferring it to the mouse in making strokes. Participants in Group 1, who used the mouse first, were relieved to discover the ease with which they can make strokes on the tablet. This explains the lower average *OPM* per trial when participants used the stylus pen than when they used the mouse.

CONCLUSION

We introduced two important factors that were missing in earlier steering law research. These are the effective width and *OPM* (Out of Path Movement). We have argued and demonstrated that removing or redoing trials where participants commit errors is not necessary or desirable in developing a model, as in real-world interaction, users commit errors and in the case of path following, occasionally wander outside the required path.

We have introduced a measure of effective width, based on movement variability in path following tasks. The correlation between the ID_e (calculated using W_e) and the movement time is higher than the correlation between *ID* (calculated using given W) and the movement time, suggesting a general improvement to steering law models build using W_e. This study does not invalidate previous experiments because in those studies, the participants had to redo a particular trial, had they committed an error. We demonstrate simply that a more natural experimental procedure may be used and that a better models results.

We have also shown that if the participants see the tunnel side lines, the *OPM* is lower than if the lines are not present.

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