An Application of the Ballistic Movement Method for Evaluating Computer Mice

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Abstract. Lin and Drury [1] validated two ballistic movement models and suggested these models could have certain benefits for evaluating input devices. Hence, the study aimed at (1) validating the application of ballistic movement models for evaluating computer mice and (2) demonstrating the superiority of this method, compared to Fitts' law. In a two-stage experiment, four participants used six types of computer mice to execute Fitts-type aiming movements and ballistic movements, sequentially. The measured data were analyzed by Fitts' law and the ballistic movement models, respectively. The comparison of the results obtained by the two methods showed that (1) ballistic movement models can well fit the measured data and (2) the ballistic movement method can provide independent performance information of "speed" and "accuracy" that is not available by applying Fitts' law. This study demonstrated an alternative method for evaluating computer mice.

Keywords: ballistic movement method, computer mouse, input device, human movements, Fitts' law.

1 Introduction

A computer mouse is one of the most effective and efficient input devices while interacting with computers. To enhance the performance of this human-machine system, researchers and designers make efforts to develop a variety of computer mice. In the development procedures, it is necessary to evaluate developing mice according to several criteria, such as production cost, durability, and usability. Most importantly, task performance is an essential criterion for assessing computer mice.

To evaluate the task performance of computer mice, Fitts' law [2] has been accepted as a useful approach, which is easy to apply and widely used. However, Fitts' law has limitations of lacking theoretical support and confounding performance of movement speed and accuracy. Lin and Drury [1] suggested a new evaluation method, called the "ballistic movement method", for evaluating input devices. They stated that the method could provide independent performance of movement speed and accuracy. However, the method has not been tested in evaluating computer mice. Hence, it is the goal of this study to test the application of the ballistic movement method, compared to Fitts' law.

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1.1 Fitts' Law

As shown in Equations 1 and 2, Fitts' law [2] predicts that the movement time (*MT*) required to execute a Fitts-type aiming movement is linearly related to the index of difficulty (*ID*) of that movement, defined as the dyadic logarithm of the quotient of amplitude of the movement and target width (Equation 2).

$$MT = a + b \times ID \quad (1)$$

$$ID = log_2 \frac{2A}{W} \quad (2)$$

where *A* is movement amplitude, *W* is target width, *a* and *b* are experimentally determined constants.

To compare two computer mice, for example, the practitioner asks participants to perform Fitts-type aiming movements manipulated at several values of index of difficulty. Fitt's law, hence, is able to describe the tradeoff relationships between the movement accuracy and speed by using two computer mice. By regressing measured *MT* data on to manipulated *ID* values for two computer mice and then drawing two regression lines on a two dimensional graph, researchers can easily compare the performance of the two computer mice. Because Fitts-type aiming movements are easily tested and the measured data can be well predict by Fitts' law, Fitts' law thus become one of the most popular evaluation methods in the domains of Human Factors and Human Computer Interaction.

Although Fitts' law is easy to apply, as mentioned in Lin and Drury [1], Fitts' law has two limitations. First, Fitts' law only allows practitioners obtain the performance information that is confounded with the two motor properties: speed and accuracy. A Fitts-type aiming movement that takes a longer movement time could result from lower motor speed, lower motor accuracy, or a combination of both. However, Fitts' law has difficulty discriminating the extent to which the two motor properties contribute to the overall movement time. Second, the application of Fitts' law has theoretical issues while reporting the throughput values and generalizing the measured results to other conditions [see 3 for detials].

1.2 Ballistic Movement Method

In recent year, the general model proposed by Lin, Drury, Karwan and Paquet [4] and Lin and Drury [5] indicates that a Fitts-type aiming movement is composed of ballistic movements, which are basic movement unit. The movement time and the endpoint variability of a ballistic movement are two essential factors that directly affect the speed and accuracy of a Fitts-type aiming movement. Lin and Drury [1] further tested two ballistic movement models for describing how these two properties are associated to ballistic movement distance.

Ballistic movement time represents the required time for performing a ballistic movement. In an experiment in which participants performed hand control movements on a drawing tablet, Lin and Drury [1] verified that Equation 6, proposed by Gan & Hoffmann [6], can effectively describe and predict the relationship between ballistic movement time ($t_{ballistic}$) and the squared root of ballistic movement distance ($\sqrt{d_u}$).

$$t_{ballistic} = i + j \times \sqrt{d_u} \quad (3)$$

where i and j are experimentally determined constants.

Ballistic movement variability describes the endpoint variability of a ballistic movement. Because of certain noise existing in human motor control mechanism, the ultimate endpoint of a ballistic movement may not exactly end at the anticipative aimed point [7, 8]. No matter endpoint errors are measured in the movement direction or perpendicular to the movement direction, Lin and Drury [1] found that the probability of endpoint location formed a normal distribution around the aimed point. In order to predict two directions of endpoint variability, Lin and Drury [1] verified the application of Equation 7, originally developed by Howarth, Beggs and Bowden [9].

$$\sigma^2 = e + f \times {d_u}^2 \quad (4)$$

where e and f are experimentally determined constants. As shown in the equation, the endpoint variability is linearly related to the square of movement distance.

The two ballistic movement models (i.e., Equations 3 and 4) have been tested in several conditions by Lin and his colleagues [1, 10, 11]. Lin and Drury [1] originally verified the two models by asking participations to perform ballistic movements using a drawing tablet. Further, the models were tested in executing three-dimensional hand movements [10] and evaluating age effects on touchscreen usage [11]. With the ballistic movement method, Lin and Ho [10] were able to evaluate three-dimensional hand movements in a detail manner in which the movement speed and accuracy could be evaluated independently. Six right-handed graduated students participated in their study. In terms of movement speed, some participants performed differently while using left hand, compared to right hand, but some kept the same no matter which hand was used. In terms of movement accuracy, however, all the participants had higher accuracy in any of the three dimensions while using their right hands. Lin, et al. [11] attempted to use the ballistic movement method for evaluating ageing difference while using a touchscreen. Although no significant difference were found on ageing effects by analysis of variance, the ballistic movement models showed that the older participants performed slower movements, but had greater movement accuracy, compared to the young participants.

1.3 Research Objective

Although Fitts' law and Fitts-type aiming movements have been widely used as an evaluation method, the method has theoretical issues and only provides confounded results of movement speed and accuracy. Nonetheless, ballistic movements are essential movement unit to construct an aiming movement. The performance of executing ballistic movements is associated to the performance of aiming movements. The two ballistic movement models introduced above separate the movement performance into "speed" and "accuracy", independently. Hence, this study aimed at verifying the ballistic movement models as a new evaluation method for computer mice. This new method was expected with superiority and more effectiveness, compared to Fitts' law.

2 Method

2.1 Participants and Equipment

Two female and two male undergraduate students, aged from 19 to 20 years, participated in this study. They were all right-handed with normal or corrected-to-normal vision.

Fig. 1. Six computer mice tested in this study

Experimental apparatus included a personal computer (PC), six types of computer mice (see Fig. 1), and two self-developed programs, comprising the Fitts-type aiming movement program and the ballistic movement program. The PC ran Visual Basic 6.0 using the developed programs that both displayed the experimental tasks and measured task performance.

2.2 Experimental Procedures

After informed consent procedures, the four participants utilized six computer mice to performed both Fitts-type aiming movements and ballistic movements. To reduce training effect, the participants had sufficient time (about 2-3 hours) to practice all the computer mice and the experimental programs. Because Fitts-type aiming movements were relatively easier to perform, all the participants executed Fitts-type aiming movements in the first stage of experiment and then executed ballistic movements in the second stage of experiment. To reduce the fatigue effect, the participants finished only a measurement that tested one computer mouse in a half-day.

To perform Fitts-type aiming movements, as shown in Fig. 2(a), the participants drew a line from the starting point to end within the target line. The movements were all performed from the left to the right. The participants were asked to complete every trial as fast as possible. If the cursor was moved over the target line, the participants needed to immediately change the moving direction and continue the movement. By clicking the cursor on any location of the screen, the participants could continue on the next trail.

To perform ballistic movements, as shown in Fig. 2(b), the participants drew a line from a starting point to the center of the cross target with a certain distance (d_u). The movements were all performed from left to right as well. The tasks started by pressing down the stylus cursor on the starting point and then moving toward the cross target. Once the cursor was moved away from the starting point, the cursor and the cross target disappeared and the movement time started to record. When the movement stopped, the cross target and the endpoint of that movement were immediately displayed on the screen. Similar to Fitts-type aiming movements, participants could continue on the next trial by clicking the cursor on the screen.

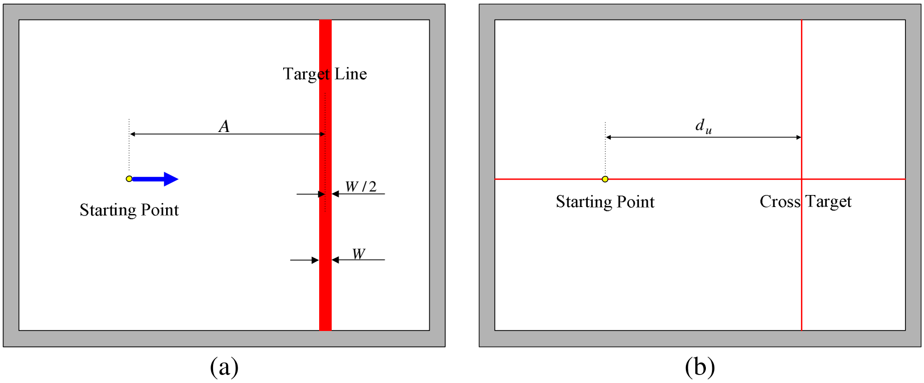

Fig. 2. The execution of Fitts-type aiming movements (a) and ballistic movements (b)

In order to reduce kinesthetic feedback caused by repetitive movements from the same starting point, there were four different starting points decided by a horizontal displacement (200 pixels) and a vertical displacements (200 pixels) in both the experiments.

2.3 Experimental Variables

In the experiment of Fitts-type aiming movement, the independent variables were Computer Mouse and *ID* and the only dependent variable were Movement Time. The four *ID* values were 2, 3, 4, and 5 bits determined by the modified Fitts' law [12, 13]. The experimental program of Fitts-type aiming movement replicated each *ID* movements 24 times, resulting in a total of 96 trials. All the trials were randomly conducted by each participant, taking about 15 minutes to finish.

In the experiment of ballistic movement, the independent variables were Computer Mouse and Movement Distance and the dependent variables were Movement Time and the movement errors measured in the movement direction (X error) and perpendicular to movement direction (Y error). The errors consisted of constant error and variable error. To analyze whether the independent variables had significant effects on these two types of errors, five replications of each experimental combination were utilized to calculate the constant error (measured by mean) and the variable error (measured by variance). However, only the results of variable error are discussed in this article. The 14 values of movement distance (d_u) were 8, 17, 32, 53, 80, 113, 152, 197, 248, 305, 368, 437, 512, and 593 pixels. The experimental program of ballistic movement replicated each movement distance 20 times, resulting in a total of 280 trials. All the trials were randomly conducted by each participant, taking about 20 minutes to finish.

3 Results

3.1 Analysis of Variance

Analysis of variance was first performed to test the effects of independent variables on dependent variables in the two experiments. In the experiment of Fitts-type aiming movement, the main effects and the interaction effect of Computer Mouse and *ID* had highly significant effects on Movement Time (all the p values < 0.001). In the experiment of ballistic movement, the main effects and the interaction effect of Mouse and Movement Distance also had highly significant effects on Movement Time and two directions of variable errors (all the p values < 0.001). Since all the main effects in the two experiments had significant effects on the dependent variables, the applications and comparison of Fitts' law and ballistic movement models were performed.

3.2 Results Obtained by Applying Fitts' Law

The means of aiming movement time (*MT*) of the six computer mouse were regressed on to the index of difficulty (*ID*) to give six regression lines. Fitts' law accounted for 98.8 % variance on average and at least 97.2 % variance of the data of movement time. The regression lines of the six computer mice are shown in Fig. 3, which shows

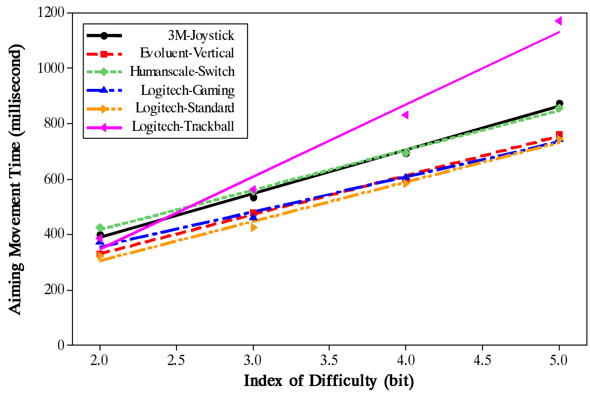

Fig. 3. Fittings of Fitts' law on aiming movement time by using six computer mice

good model fittings. In general, the movement times required to execute aiming movements are close while using the computer mice of Logetich-Standard, Evoluent-Vertical, and Logitecfh-Gaming, which had the best performance compared to the rest. However, the computer mouse of 3M-Joystick required the longest movement time for executing aiming movements, especially when the value of index of difficulty were greater than three.

3.3 Results Obtained by Applying the Ballistic Movement Method

The means of ballistic movement time ($t_{balllitic}$) of the six computer mouse were regressed on to the square root of ballistic movement distance ($\sqrt{d_u}$) to give the slopes and intercepts. The model fitted the data very well. It accounted for 96.2 % variance on average and at least 85.6 % variance of data of ballistic movement time. The regression lines of the six computer mice are shown in Fig. 4, which also shows good model fittings. As shown in the figure, the movement times required to execute ballistic movement were close by using the computer mice of Evoluent-Vertical and Logitech-Trackball, which resulted in the fastest movements. The ballistic movements were also fast by using the computer mice of Humanscale-Switch and Logitech-Gaming. However, the computer mouse of 3M-Joystick resulted in the slowest ballistic movements.

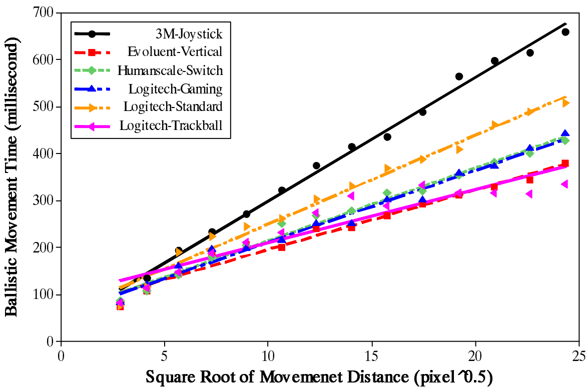

Fig. 4. Fittings of the ballistic movement time model by using the six computer mice

The two error variances, calculated from the raw data for each distance, were regressed on to ${d_u}^2$ to give the slopes, intercepts, and $\boldsymbol{r^2}$ values. For X-variable error (${\sigma_X}^2$), the ballistic movement time model accounted for 93.0 % variance on average and at least 85.5 % variance of data. For Y-variable error (${\sigma_Y}^2$), the ballistic movement time model accounted for 90.4 % variance on average and at least 76.1 % variance of data. The regression lines of X-variable error and Y-variable error are shown in Fig. 5, where X-variable error is about ten times larger than Y-variable error. In terms of X-variable error (measured in the movement direction), the six computer mice listed in descending order by endpoint variance were Logitech-Trackball, Humanscale-Switch, Evoluent-Vertical, 3M-Joystick, Logitech-Gamming, and Logitech-Standard. The computer mouse of Logitech-Standard resulted in the smallest X-endpoint variance, and the computer mouse of Logitech-Trackball resulted in the greatest X-endpoint variance. In terms of Y-variable error (measured perpendicular to the movement direction), the six computer mice listed in descending order by endpoint variance were 3M-Joystick, Logitech-Trackball, Humanscale-Switch, Logitech-Gamming, Evoluent-Vertical, and Logitech-Standard. Again, the computer mouse of Logitech-Standard resulted in the smallest Y-endpoint variance. The computer mouse of Logitech-Trackball also had great Y-endpoint variance, but the computer mouse of 3M-Joystck had the greatest Y-endpoint variance.

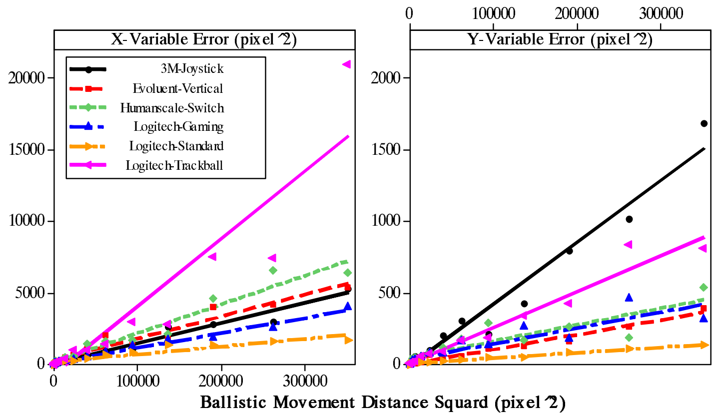

Fig. 5. Fittings of the ballistic movement variability model on the error variance by using the six computer mice

4 Discussion

This study first showed that the ballistic movement model, as Fitts' law, have good predictions of the measured data. Fitts' law, as expected, well predicts the relationship between the movement time and the index of difficulty while using each computer mouse to execute Fitts-type aiming movements. The two ballistic movement models also well predict the relationships between the measured data of ballistic movement time, X-variable error, Y-variable error and the movement distance. Although the fittings of the models were not as good as that of Fitts' law, the models accounted for 96.2 %, 93.0 %, and 90.4 % of three types of data variance, respectively.

While the evaluation results of the two methods were compared, this study then showed the superiority of the ballistic movement method. By applying Fitts' law, we can easily obtain the movement times required by each computer mouse to finish aiming movements set at a certain *ID* value by comparing the linear regression lines obtained by Fitts' law. However, as mentioned previously, the movement time obtained by Fitts' law is confounded by two motor properties of speed and accuracy. Two computer mice may require same aiming movement times to operate, but they may possess different combinations of speed and accuracy properties. By applying the ballistic movement method, we can further obtain independent performance of speed and accuracy properties of each computer mice by comparing the linear regression lines obtained by the ballistic movement models. This superiority is fully supported by our results. For example, by applying Fitts' law, we only know that the computer mice of Logitech-Standard and Evoluent-vertical required close movement times to operate Fitts-type aiming movements (see Fig. 3). However, the application of ballistic movement method showed these two computer mice possess different combination of speed and accuracy properties. The computer mouse of Logitech-Standard had better performance of accuracy (see Fig. 5), but had poor performance of speed than the computer mouse of Evoluent-vertical (see Fig. 4). Moreover, by applying Fitts' law, we know that the computer mouse of Logitech-Standard required shorter movement times compared to the computer mice of Evoluent-Vertical and Logitech-Gaming. However, Fitts' law provides no information whether the good performance of Logitech-Standard is due to its speed property or accuracy property. By using the ballistic movement method, as shown in Fig. 4 and Fig. 5, we realize that the reason why the mouse of Logitech-Standard required the shortest movement time was not due to its speed performance, but due to its highest accuracy performance. Finally, by applying the ballistic movement method, we know the reason why the computer mouse of Logitech-Trackball required the longest movement time was not due to its speed property, but due to its accuracy property that was the worst among the six computer mice.

Future research should validate the ballistic movement method in a comprehensive way by recruiting adequate participants and controlling driver difference of computer mice. Furthermore, the independent performance of speed and accuracy could help designers focus on specific properties of computer mouse for improvement.

5 Conclusions

This study attempted to validate the two ballistic movement models proposed by Lin and Drury [1] as an alternative method for evaluating the task performance of computer mice. To this end, six types of computer mice were tested by simultaneously applying both Fitts' law and the ballistic movement method. By comparing the results obtained by the two methods, we showed the superiority of the ballistic movement method, compared to Fitts' law. Fitts' law only helps determine the time required performing Fitts-type aiming movements for each computer mouse, whereas the ballistic movement method provides independent performance information about speed and accuracy, which could help effectively improve the design of computer mouse in the future research.

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