Modeling of Human's Pointing Movement on the Effect of Target Position

Junmin Du, Haiwen Shi, and Xiugan Yuan

Institute of Human-Machine-Environment Engineering,
Beijing University of Aeronautics and Astronautics, 100083 Beijing, China
{JunminDu,adujm}@126.com

Abstract. The purpose of this study is to construct a new pointing movement model considering the effect of target position. A pointing movement experiment was designed and carried out, and the pointing movement characteristics when human upper limb touched the targets on front board are studied. The result shows that the starting point position and target position greatly affect the movement time. A new pointing movement model is built, in which the effect of target position is introduced. The new model obtains higher contribution value and could describe the data better than the conventional models.

Keywords: Human upper limb, pointing movement, Mathematic model.

1 Introduction

The research of the pointing movement started in 1950's. According the information theory, Fitts[1] and others studied the relationship between target distance and movement time in one-dimensional movement, and brought the famous Fitts law first and foremost. After then, many researches extended the Fitts law from various aspects, and the research for pointing movement was also extended from one-dimensional to three-dimensional. As a result, some performance models of two-dimension and three-dimension pointing movement tasks were constructed [2-7]. However, these mathematic models were all built based on the immovable starting point. While the starting point usually has different position in practice. It is therefore the purpose of this study focuses on the experiment, and to construct a new model which considering the effect of the target position on movement time.

2 Methods

2.1 Subjects

21 male graduate students, who had neither musculoskeletal abnormalities nor optical disorders, participated in the experiment. The subjects were all right-handed. Their mean (SD) age, height and weight were 23.8 (2.0) years, 1.726 (0.021) m and 64.4 (5.3) kg respectively.

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2.2 Design and Procedure

The whole pointing procedure is captured with Vicon motion tracking system. The sketch map of pointing experiment is shown as Fig.1. The target board is fixed on a table, and the board has 17° obliquity from a vertical plane. The subject is required to sit on a chair in front of the target board. The height and location of the chair is adjustable so that the subject could pose comfortable and meet the experiment requirements. The subject's body vector plane is superposed with the board perpendicularity line crossing the board centre point.

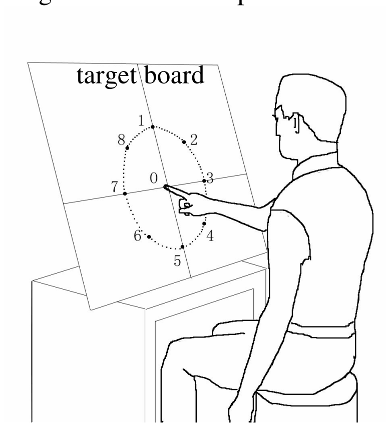

Fig. 1. The sketch map of pointing experiment

The location of nine target-circles is shown in Fig.2. Those target-circles' diameter are all 0.4m. The target-circles are arranged regularly for three rows and three columns. The O1~O9 signed in Fig.2 are the location of the center of target-circles. Eight targets scatter homogeneously on the circumference, as shown in Fig.3. In order to alleviating the vision interference, nine target-circles are drawn on six pictures according their location on the board, and there are only one or two target-circles on the board when the experiment is performed.

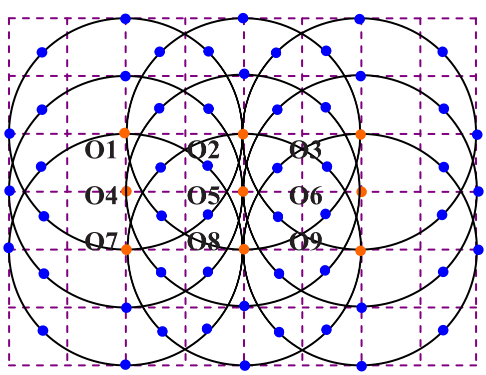

Fig. 2. The location of the target-circles on the board

Before the experiment start, each subject was aware of the experimental procedure. During the experiment, the subject must keep the shoulder steadily, if the subject's body posture is changed or shoulder moves greatly or touches wrong target, the experiment is abnegated and redo again. At the beginning of the experiment, the subject's index fingertip touches the center of a target-circle, which is the starting point. Subjects are instructed to carry out the movement as accurately and as quickly as possible. For the eight target points on one target-circle, the pointing order is clockwise, and each target point is touched three times by each subject.

The experimental factors include as the following:

(a) the distance from the starting point to the target point: 0.2m.

(b) the target shape and size: solid round with diameter of 0.013m.

(c) the approach direction from the starting point to the target point: take the line from target-circle center to 3rd target point as the datum line, define the 3rd angle as 0°. The angle of target points increase by anti-clockwise, shown as Fig.3.

(d) the direction of target-circle center: define the center line of middle column target-circles (O2-O5-O8) as datum line, the left forward direction set as negative, the right as positive.

(e) the distance between target-circles center: for row the distance is 0.1m, for column the distance is 0.2m.

(f) the position of target-circles: define the center line of middle column target-circles (O2-O5-O8) as datum line, the left forward direction set as negative, the right as positive.

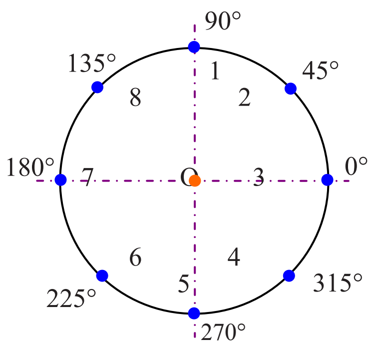

Fig. 3. The distribution of the targets on a single target-circle

3 Results

3.1 Fitting the Data to the Conventional Pointing Movement Model

Fitts law is a classical model for predicting one-dimensional pointing movement. MacKenzie[2] improved the Fitts model, and extended it to two-dimensional pointing movement, the formula is

$$t = a + b \bullet \log_2(2x/s + 1.0) \tag{1}$$

where x is the distance from the starting point to the target point, s is the target size, a and b are regression coefficients. The log term ($log_2(2x/s+1.0)$) in Eq.(1) indicates the index of difficulty(*ID*), viz. $ID=log_2(2x/s+1.0)$.

Based on Eq.(1), Iwase and Murata[5,6] built a three-dimensional pointing movement model of human body upper limb with considering the affect of approach direction to the target:

$$t = a + b \bullet \beta(\theta) \bullet \log_2(x(\theta)/s + 1) \quad (2)$$

where $\beta(\theta)= log_e 2\cdot(x(\theta)+s)/(b\cdot v(\theta))$, $x(\theta)=x\cdot\{(1+ a\,(sin\theta+1)\ \}$, a is a positive constant number, θ is the approach direction angle from starting point to target, which defined as shown in Figure3, $v(\theta)$ is mean velocity of pointing movement, a and b are regression coefficients. $ID=log_2(x(\theta)/s+1.0)$.

Compared with other conventional models, Eq.(1) and Eq.(2) could describe two-dimensional and three-dimensional pointing movement better[5,6]. So the two

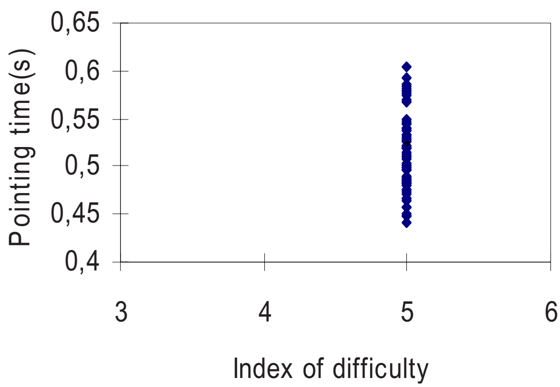

Fig. 4. Relationship between the index of difficulty and the pointing time using Eq.(1) (*R2= 4E-14*)

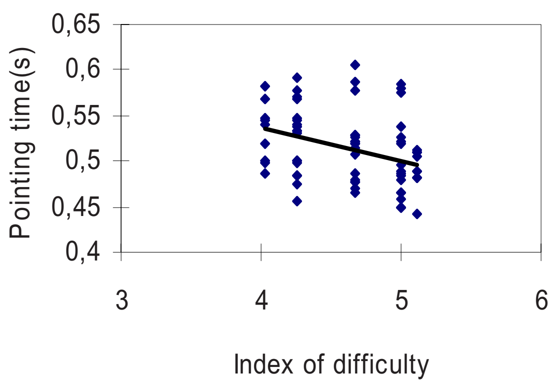

Fig. 5. Relationship between the index of difficulty and the pointing time using Eq.(2) (*R2= 0.1123*)

equations are used to do the linear regression of the experiment data. Fig.4 and Fig.5 are the relationship between the index of difficulty and the pointing time using Eq.(1) and Eq.(2). The contribution rates of the regression equation are very small, one is $R^2=4E\text{-}14$ and another is $R^2=0.1123$, which indicates that Eq.(1) and Eq.(2) cannot satisfy the demand of the experiment data. According to the experimental conditions, the distance from starting point to the target point x and the target size s are constant numbers, so x/s is constant. Although the approach direction is considered in Eq(2), the equation can't fit the data yet. The difference of target-circles position are not mentioned in Eq(1) and Eq(2), that's the main reason that the equations can't fit the experiment well.

3.2 Analyzing the Discipline of Pointing Movement Time

Fig.6 and Fig.7 reveal the pointing time of middle column target-circles and middle row target-circles respectively.

The significance test result reveals that the pointing time of eight targets on the same target-circle is significant ($p<0.05$, $a=0.05$). It means that wherever the target-circle

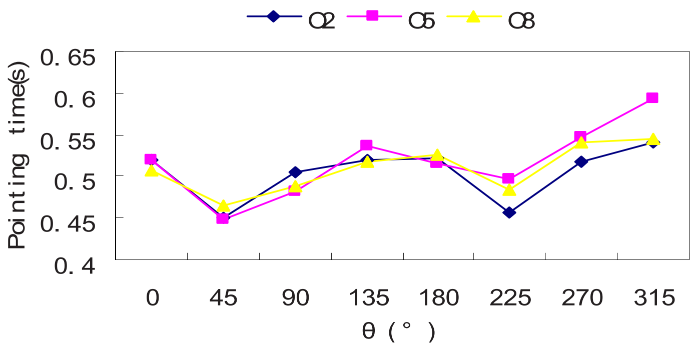

Fig. 6. The pointing time of middle column target-circles

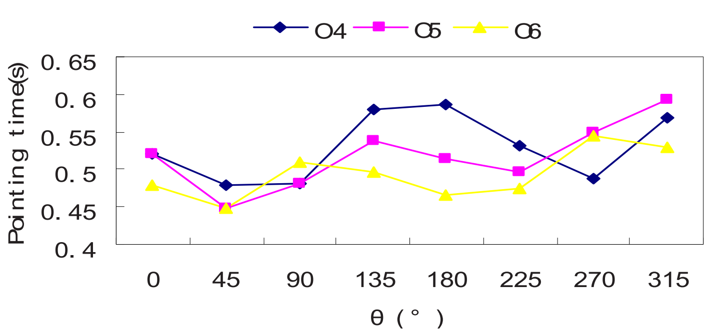

Fig. 7. The pointing time of middle row target-circles

is located, the pointing time of targets scattered on a same target-circle are different. This difference is mainly caused by the distinction of approach direction to the target. The significance test on the pointing time of the targets with same approach direction shows that the difference is insignificant when the target-circles in a column line, and the difference is significant when the target-circles in a row line. Fig.6 and Fig.7 could testify these results. In a column, the pointing time of the targets with same approach direction are very close and have no significant difference, so the pointing time could be regarded as equally. While in a row, the pointing time is strongly affected by the location of the target-circle. These analyses suggest that when structuring the new pointing movement model, it is necessary to consider the effect of the approach direction to the target as well as the target-circle location in the row, while the effect of the target-circle location in column could be ignored.

3.3 Constructing the New Pointing Movement Performance Model

First of all, introduce the approach direction from the starting point to the target into conventional Fitts model. The Fitts model is:

$$t = a + b \bullet \log_2(2x/s) . \tag{3}$$

Fig.6 is the pointing time of the target-circles in the middle column. Because the relationship between the approach direction and the pointing time is similar to the sin curve, we define the *sinθ* and *sin2θ* as the factors. Then the index of difficulty (ID) is revised as:

$$ID = [\log_2(x/s) - \sin(2\theta)][1 - k_1 \sin\theta] . \tag{4}$$

where K_1 is a constant positive number according to the data, θ is the approach direction angle.

Fig.2 reveals the relative position of the nine target-circles. Set the target-circles center line of middle column as the datum line, the target-circles in the left and the right column have different directions and have certain distance from the datum line. The different directions and distance contribute greatly to the pointing time difference. Define the direction of target-circle center and the distance between target-circles as the factors, and induct them into Eq.(4), then Eq.(4) could be improved to the following expression:

$$ID = [\log_2(x/s) - \sin(2\theta)][1 - k_1 \sin\theta] - k_2(\cos\theta + k_3) . \tag{5}$$

where K_2 is the target-circle center distance coefficient, which is defined by the relative distance of target-circles, K_3 is the target-circle center direction coefficient, which is defined as: $K_3 = -1$ when target-circle is in the left column, $K_3 = 0$ when target-circle is in the middle column, $K_3 = 1$ when target-circle is in the right column.

Fig.7 shows that, compared with the middle target-circle (O5), the pointing time of the left and the right target-circle (O4 and O6) have certain offsets. The offsets are caused mainly by the different locations of target-circles. Accordingly, a target-circle location modified item should be inducted in Eq.(5). So the Eq.(5) could be revised as:

$$ID = [\log_2(x/s) - \sin(2\theta + \alpha)][1 - k_1 \sin(\theta + \alpha)] - k_2(\cos\theta + k_3) \quad . \quad (6)$$

where a is target-circle location modified coefficient, which has the same sign as K_3.

According to Eq.(6), a new performance model that considering the effect of starting point and target position could be obtained:

$$t = a + b \bullet [\log_2(x/s) - \sin(2\theta + \alpha)][1 - k_1 \sin(\theta + \alpha)] - k_2(\cos\theta + k_3) \quad . \quad (7)$$

where a and b are regression coefficients, x is the distance from the starting point to the target, s is the target size, θ is the approach direction from the starting point to the target, K_1 is a constant positive number according to the data, K_2 is the target-circle center distance coefficient defined by the relative distance of target-circles center, K_3 is the target-circle center direction coefficient ($K_3 = -1$ when target-circle is in the left column, $K_3 = 0$ when target-circle is in the middle column, $K_3 = 1$ when target-circle is in the right column), a is target-circle location modified coefficient with the same sign as K_3.

Fig.8 shows the relationship between ID and pointing time using Eq.(7). The contribution rate of the regression equation ($R^2 = 0.751$) is much higher than that in Fig.4 and Fig.5. The new model could describe the data better than the conventional Fitts' models.

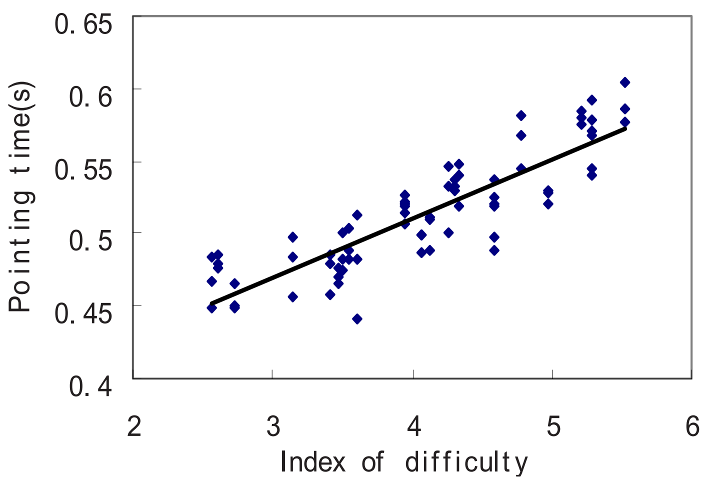

Fig. 8. Relationship between the index of difficulty and the pointing time using Eq.(7)(*R2= 0.7516*)

4 Conclusions

In this paper, a new performance model of pointing movement has been constructed, which is mainly based on the consideration of the effect coming from the starting point and the target position. Several factors have been introduced into the model, such as the approach direction from the starting point to the target, the target-circle center distance coefficient, the target-circle center direction coefficient, the target-circle location modified coefficient and etc. The new model could describe the data better than the conventional models.

References

1. Fitts, P.M.: The information capacity of the human motor system in controlling the amplitude of movement. Journal of Experimental Psychology 47(6), 381–391 (1954)
2. MacKenzie, I.S., Buxton, W.: Extending Fitts Law to Two-Dimensional Tasks. In: Proceedings of the CHI'92 conference on Human Factors in computing Systems. New York, pp. 219–226 (1992)
3. Mutata, A.: Empirical Evaluation of Performance Models of Pointing Accuracy and Speed With a PC Mouse. International Journal of Human-Computer Interaction 8(4), 457–469 (1996)
4. Yang, N.F., Wang, R.C., Jin, D.W.: Evaluation method of human upper limb movement function based on Fitts' law. Chinese journal of rehabilitation medicine 16(6), 336–339 (2001)
5. Iwase, H., Murata, A.: Modelling of human's three-dimensional movement-Extending Fitts' model to three-dimensional pointing task. In: IEEE international worksop on robot and human interactive communication, 594–599 (2001)
6. Murata, A., Iwase, H.: Extending Fitts' law to a three-dimensional pointing task. Human Movement Science 20, 791–805 (2001)
7. Zhai, S., Kong, J., Ren, X.: Speed-accuracy tradeoff in Fitts' law tasks – on the equivalency of actual and nominal pointing precision. International journal of human-computer studies 61, 823–856 (2004)