A New Manipulative Approach to Scrolling with the Mouse Wheel

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Abstract: Scrolling plays an important and substantial role in today's graphical user interfaces. In this study we introduce a new approach to scrolling acceleration – the dual-acceleration mode. This method combines wheel acceleration and cursor-position acceleration operations to allow instant scrolling speed control with an increase in overall efficiency. Twenty-two subjects were tested in a scrolling-based task efficiency experiment, using three types of control modes: the Level mode, the Wheel Acceleration mode and the Dual Acceleration mode. Research results show that our acceleration approach has considerable strength in increasing the task efficiency of aiming from the medium-far distance with no significant increase in the error rate. In contrast with existing acceleration models, our Dual-Acceleration approach allows (1) larger room for speed change and (2) users to adjust and adapt the appropriate scrolling speed for different conditions, such as slow-speed scrolling for precise reading and higher speeds to increase efficiency for long-distance page changes.

Keywords: interaction design, navigation, scrolling, mouse wheel

1. Introduction

In present day graphical user interfaces (GUIs), scroll bars are the most commonly used tools for controlling the information presented on a single page for visual display devices. Others include hand tools and dynamic speed control mode used with the middle key of the mouse. User control of the scroll bar consist of two major methods: (1) the mouse cursor approach, such as clicking on the scroll bar end arrows, dragging the scroll bar body, or clicking on the blank space between the scroll bar body and the end arrows; and (2) the mouse wheel approach by rolling the wheel, vertically or horizontally, to change the position of the scroll bar. In addition, the keyboard approach, which uses the Scroll Lock key and arrow keys, is the legacy third method that is now rarely used in modern systems and has been, in all but a few specialist cases, replaced by the two mouse approaches. The first approach has the inherent disadvantage of requiring the user to move the mouse cursor over the scroll bar, causing the shifts in the user's perception and motion response attention away from the original working target [1]. It also increases the frequency of cursor movements and the number of operations for aiming work. Overall, the mouse cursor approach to scrolling lowers the efficiency of work and increases the workload for users. In contrast, the mouse wheel approach allow much easier page scrolling as it provides users the freedom to scroll the page independently of moving the cursor. This eliminates potential distractions, avoids unnecessary operations, and hence is more instinctive and efficient for users.

The common mouse wheels operate on a set speed mode, returning a set value output with every rolling graduation. We can also find automatic scrolling acceleration modes used with specific drivers and MAC operation systems in the market. Under this mode, rolling the wheel would produce different rolling distances according to the wheel speed; the faster the wheel rolls the larger the unit movement. Hinckley et. al. researched into the above wheel modes and pointed out that set-speed wheels were only appropriate for short distances whereas different rolling speed modes were appropriate for different distance conditions[2]. Automatic scrolling acceleration has limitations in the switching between high and low speeds. A high-speed acceleration mode reduces operation control and burdens the user vision, which may eventually cause user fatigue. In addition, the large range page jump increases the work load and content search time, which limits its overall effectiveness. The hand-scrolling mode, on the other hand, is intuitive in terms of user control. It consists of a hand tool which simulates natural human behavior as clicking of the mouse causes the hand cursor to “grab” the page content and allow the user to drag the viewing position using the mouse. It also has a Control-Response ratio of 1, which is appropriate for precise work, such as graphical applications and PDF files. The position-acceleration mode allows the user to control the speed of scrolling [3]. Upon clicking the middle mouse button, the cursor changes into a two-way or four-way arrow mark and the user may control the speed and direction by moving the cursor. The scrolling speed is calculated using the relative distances between the instantaneous and initial positions of the cursor, which is often classified as (first-grade) speed control. However, this approach tends to easily confuse users that are not familiar with the scrolling mechanism.

In this research, we analyze the control and operation characteristics of present computer interface scrolling modes, using scroll bar and mouse wheel operation arrangements as the basis to introduce a new type of scrolling acceleration mode. This new control mode aims to be extensive and instant, in order to increase the total efficiency of scrolling operations. We used scrolling-based aiming tasks to compare the operation efficiency of our new scrolling acceleration approach with the results using the set-speed and automatic scrolling acceleration modes at six different distances.

2. Method

2.1. Participants

Twenty-two healthy subjects, 50% male, 50% female and aged between 20 and 30 (23.14±1.64 years old), participated in the experiment. All subjects were right handed, had no major diseases or injuries to the hand or eye, and had at least three years experience.

2.2. Experiment design

This research contains two experimental parts with three types of scrolling acceleration modes versus six different moving distances in order to test the efficiency of scrolling-based aiming tasks. We eliminated the possibility of the scanning condition during the browsing operation to simplify the experiment design and used scrolling-based aiming tasks to evaluate task efficiency of the three types of scrolling acceleration modes. We keep a record of the task time and error rate for computation and analysis.

The three types of scrolling acceleration mode are as follow: (1) Level mode, ST: the scrolling speed is set as to a fixed preset value at v = 3 line/notch; (2) Wheel Acceleration mode, WA: the unit distance moved is relative to the wheel rolling speed; the faster the rotation of the mouse wheel the larger the unit distance covered. The detailed formula for the wheel speed-distance moved relationship is: $\Delta y = v*(1+k/\Delta t)^a$ where "v" is set as the lowest speed of 3 line/notch, "k" is the speed-adjust factor and "a" is the acceleration factor; (3) Dual-acceleration mode, DA: this approach consists of two acceleration operations, wheel acceleration and position-based acceleration. The wheel acceleration operation: the faster the wheel speed the longer the unit distance moved (Fig.1); the position-based acceleration: acceleration operation proceeds according to the vertical coordinates of the mouse cursor, the higher the position of the cursor the higher the acceleration and vice versa. The position change formula is: $\Delta y = a_p * v*(1+k/\Delta t)^a$ where a_p = x, when the y coordinates of the mouse cursor is $\leqq 1/4$；$a_p = 1$，when the y coordinates of the mouse cursor is $\geqq 3/4$}. The $a_{p\ value}$ is determined by the vertical position of the mouse cursor, the acceleration scale is at 1/2 the vertical height of the monitor (Fig. 2). The six distances include 144, 288, 432, 576, 720, and 864 (line).

The first part of the experiment tests the aiming task efficiency of the three scrolling-acceleration modes at five distances: 144,288,432,576,720. The second part of the experiment tests the aiming task efficiency of the three modes at the distance of 864.

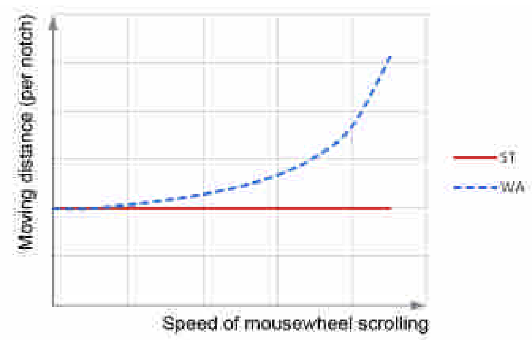

Fig.1 Scroll speed and wheel speed relationship

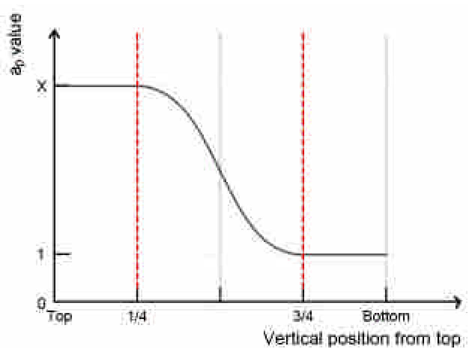

Fig.2 Position-based acceleration and vertical position control

2.3. Task design

The experiment task is a scrolling-based aiming task. A scroll bar cursor appears at the top of the scrolling interface at the start of each task and subjects control the scroll bar cursor position with the mouse wheel. Subjects must move the scroll bar cursor into the red target region and press the enter key to complete the task; a timer records the time elapsed between the subject's initial rolling and when the enter key is pressed; subjects were told in advance that the cursor must be fully within the target region in red and the enter key must be pressed in order to successfully complete the task. If the enter key is pressed when any part of the cursor is outside the target region, the event is counted as an error.

The first part of the experiment is divided into the three types of scrolling-acceleration modes. Each group consists of five different moving distances with ten aiming tasks each, at a total of 50 aiming tasks. In order to consider the learning effect of task speeds under different scrolling acceleration modes [2], the ten aiming tasks for each moving distance appears successively and randomly. The three modes also appear in a random experiment order. The second part of the experiment proceeds the same way as the first part, with only one distance of 864. Before each experiment, a brief introduction is given to the participants and 20 practice aiming tasks are given before the formal experiment. There is a three minute break between the two parts of the experiment.

3. Results

3.1. Task time analysis

The first part of the experimental data consists of 22 subjects each with $3 \times 5 \times 10 - 150$ sets of task data. Table 1 shows the average task time for the three scrolling acceleration modes under different distances. Figure 3 enlarges the graph in part. The data is grouped according to distance and analyzed with one-way ANOVA to compare the efficiency differences between the ST, WA and DA modes. Only distance level 288 passed the test for Homogeneity of Variances and the task efficiency of the three scrolling acceleration approaches were examined with Scheffe's multiple comparison method. However, the other four distance groups, 144, 432, 576 and 720, did not fulfill the homogeneity of variances presumption for the test; instead, they were examined alternatively with Dunnett's T3 method.

The results of showed significant differences ("p" values of less than 0.05) in task time between the ST and WA modes of scrolling acceleration at all distance levels (144, 288, 432, 576 and 720.) We also showed a significant difference ($p < 0.05$) in task time for the ST and DA modes at all distance levels. At distance levels 144, 288, 432 and 576, the results demonstrated no statistical difference ($p > 0.05$) between WA and DA modes. At distance 720, a significant difference ($p < 0.05$) in task time between DA and WA modes is shown. Furthermore, we also demonstrated that the task time for the DA mode is shorter than that of the WA approach.

3.2. Error rate analysis

Table 4 lists the number of errors made by all subjects for each mode and distance level. The Chi-squared test is used to examine the relationship between error rate, acceleration mode and distance levels. Crosstabs of error frequency to modes and error frequency to distance levels (Table 2, 3) are made. The results of the Pearson Chi square test show that there is no significant relationship (sig. value = 0.67 > 0.05) between error frequency and different acceleration modes. In addition, we showed no significant link (sig. value = 0.67 > 0.05) between error frequency and distance levels.

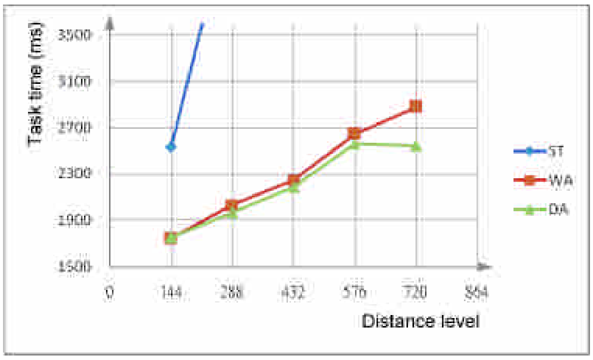

Fig.3 Mean task time under 5 distance level (Partially enlarged)

Table1. Mean task time and error time under 6 distances (ms)

Movement / Modes	144	288	432	576	720
ST	2534	4610	6660	8765	10621
WA	1743	2033	2248	2645	2878
DA	1755	1970	2187	2560	2545

Table2. Crosstab between error frequency and scrolling modes

Error frequency	Modes			Total
	ST	WA	DA	
1	1	0	0	1
2	0	0	2	2
3	1	2	0	3
4	1	0	0	1
5	2	2	2	6
6	0	1	1	2
Total	5	5	5	15

Table3. Crosstab between error frequency and distance levels

Error frequency	Distance levels					Total
	144	288	432	576	720	
1	0	0	0	1	0	1
2	0	0	1	0	1	2
3	1	1	0	0	1	3
4	1	0	0	0	0	1
5	1	2	1	1	1	6
6	0	0	1	1	0	2
Total	3	3	3	3	3	15

Table4. Total Errors

Errors		Modes			Total
		ST	WA	DA	
Distance Level	144	4	3	5	12 (20.00%)
	288	5	3	5	13 (21.67%)
	432	5	6	2	13 (21.67%)
	576	1	5	6	12 (20.00%)
	720	3	5	2	10 (16.67%)
Total		18 (30.00%)	22 (36.67%)	20 (30.33%)	60 (100.0%)

3.3. Task efficiency analysis of distance level 864

From figure 3.1 we can see a sharp turn in the task time between distance levels 576 and 720 with the DA mode. Therefore, we introduced the distance level 864 in part 2 in order to further examine the task efficiency tendency characteristics under the three acceleration modes at larger distances levels.

Fifteen subjects participated in the second part of the experiment operating under ST, WA and DA modes with 20 scrolling-based aiming tasks at distance level 864. Each subject is required to complete 60 aiming tasks. The descriptive statistics of the experiment results are shown in Table 1. The results showed no support for the homogeneity of variances (sig. value < 0.05) between acceleration mode and task time using ANOVA analysis; therefore, we examined the case using Dunnett's T3 method. Our results show significant differences between the three scrolling acceleration modes at distance level 864. The accumulative error frequency is 20 times using the DA mode, 15 times with the WA mode and none for the ST mode (Table 1).

4. Discussion

4.1. Discrete movement of scrolling

We can see that aiming tasks can be separated into two stages, rough adjustment (travel time) and precise adjustment (adjust time) [4]. For general continuous aiming tasks, such as moving the mouse cursor to click on a target, most of the aiming efficiency is achieved in the precise adjustment phase: users initially move the cursor near the target area using rough estimation and only then they aim for the target precisely, just before clicking (Fig. 4a). However, for wheel-controlled scrolling tasks, the efficiency is affected even during the rough adjustment stage due to the discrete nature of the tasks and movements. The maximum position shift for each rolling action, ΔD maximum (Fig. 4b) determines the maximum scroll bar movement speed, which is the main limitation factor for efficiency during the rough adjustment stage. In this research, the unit speed for the ST mode is 3lines/notch; the low set speed reduced the unit position shift and time scale differences between the rough and precise adjustment stages, which severely limits the efficiency of longer scrolling distances where the rough adjustment stage is more pronounced. In contrast, the position shift formula for the WA and DA modes is calculated as a maximum and minimum speed range. The larger the available range for unit position shift and time ratios, the better the separation between the rough and precise adjustment stages. Hence, a larger range allows closer approximation to a continuous aiming task mode (Fig. 4b) better efficiency at larger scrolling distances.

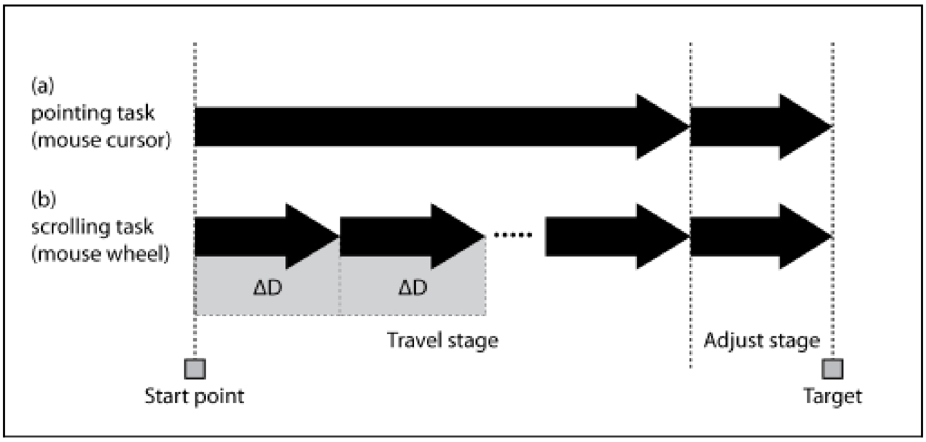

Fig.4 Continuous movement versus discrete movement

From the analysis of task time efficiency, we can see significant differences between ST, WA and DA modes; we standardize the average task time using data from the ST mode and obtain a ratio for task efficiency (Fig. 5**)**. The WA and DA data tendency graph (Fig. 6) shows the efficiency growth rate reduces with increasing distance. This could be explained with the aforementioned concept: the maximum unit shift is limited to a fixed value for our experiment; and, hence, the larger the moving distance, the larger the ratio difference between the set value and shifting distance, which allows for greater influence of the discrete nature of scrolling.

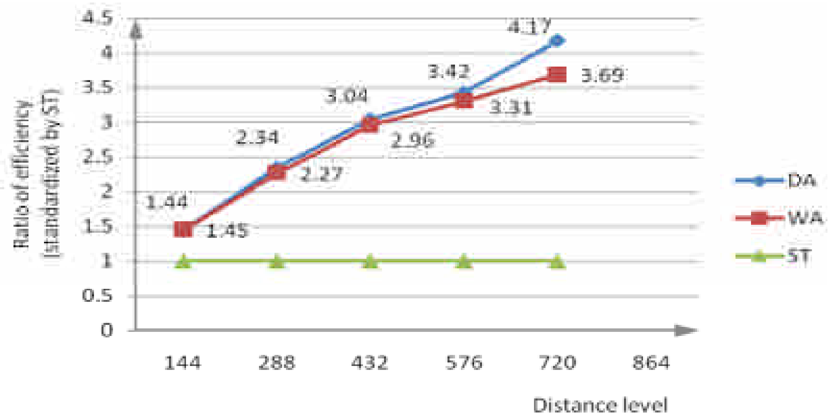

Fig.5 Task efficiency ratio based on the ST mode standardization

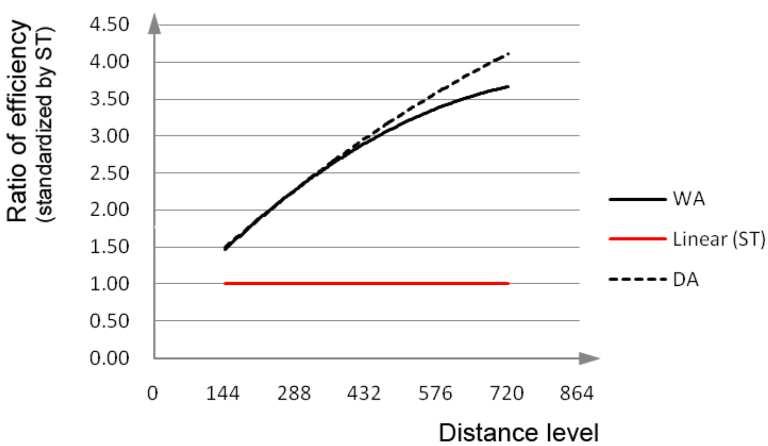

Fig.6 Tendency graph for the task efficiency ratio

4.2. Stability

We found individual variance differences in the learning effect for the three modes. Under the ST mode, the group difference of task time and distance is minor, while taking the subjects as individual units. However, for the DA mode, the individual differences are relatively more prominent. We suggested some possible reasons for these differences by analyzing the data and observing subjects during the experiment. We found that occasional occurrences of extremely low task times, which we term “lucky hits” was the one of the major factors under the WA mode. These are caused by coincident “lucky hits” during the rough adjustment stage which completely eliminates the precise adjustment stage. In addition, poor speed control by the user was a second major source of differences. As the speed cannot be precisely controlled by individuals in the WA mode due to a non-fixed wheel-move to scrolling ratio, users typically experienced unpredictable cursor movement during scrolling. Results from the DA mode showed greater effects of individual variation, which implies lower control stability. Many subjects of the experiment also mentioned being disturbed by the excessive acceleration under the DA mode, as the cursor movements far out of the predicted range prompts them to use a lower, and thus more manageable, speed for the DA mode. However, we observed no significant difference in error rates between the three modes, which implied that control stability has no significant effect on task efficiency

4.3. Control-response ratio in scrolling (C/R ratio)

The concept of control-response ratio [4] is often introduced when discussing the efficiency of pointing input tasks. In general, a low C/R ratio implies a higher efficiency at the rough adjustment stage. However, the overall efficiency is also dependent on the efficiency at the precise adjustment stage. It is a control concept; using the wheel-controlled scroll bar task mentioned previously, the larger the area shifted with each rolling movement represents a lower C/R ratio. Theoretically, there is an ideal C/R ratio at every distance level. However, we can see from Table 1 that the task efficiency-distance relationship of the two modes shows a linear correlation, which significant effect on the C/R ratio. It is speculated that the distance levels applied in this research are beyond the distance sensitivity of the two speed modes, and hence we cannot analyze the task efficiency of the two modes using the C/R ratio alone. An alternative method of measuring task efficiency is by using the error rate, as we have done in this research. We have found no significant statistical difference in error frequency recorded between the WA, DA and ST modes. Therefore, from the results we can see that the overall performance efficiency of the DA mode is higher than that of the WA and ST modes. This further supports the idea of applying speed control to present day computer interfaces may increase the efficiency of scrolling tasks.

During this research, we examined the nature of scrolling tasks, observed experimental procedures and analyzed the performance efficiency to find that scrolling tasks are discontinuously and discretely controlled. One of the factors which may affect the efficiency of scrolling includes the limited movement space of a single shift as mentioned above. Another possible factor is the limitation in shifting frequency, which is the frequency of rolling the wheel using the human fingers present mouse wheel designs allow approximately 8-10 rolling “clicks” with each finger movement. Hardware limitations include the external diameter of the wheel, the exposed ratio and the wheel reaction response. The control finger requires recovery time after every rolling movement, during which the time elapsed has no contribution to the task, it lowers the overall efficiency. This becomes particularly prominent during the rough adjustment stage where finger recovery time consumes a relatively high ratio of total time. It is a factor worth considering for future investigations. Tests of the scrolling speed control mode, such as those used in this research, allow the comparison of the difference in task efficiency. Further experiment designs may also consider the effect of wheel input frequency and finger movement frequency in order to better analyze the nature of scrolling tasks.

5. Conclusions

Scrolling tasks are discrete processes, unlike general continuous pointing tasks. The factors that affect task efficiency are limited by touch-movement control. In this research, we used simple scrolling-based aiming tasks to analyze the performance efficiency of three scroll acceleration modes. The new type of acceleration approach, which we term the dual-acceleration (DA) mode, introduced in this research increases the efficiency of scrolling-based aiming for medium and far distance levels with no significant increases in the overall error rate. Comparing our approach with other present acceleration modes, we can see that (1) the DA mode allows a larger range of acceleration, allowing a better approximation to a continuous movement model; hence, it increases the efficiency of the rough adjustment phase and the overall performance efficiency; (2) it includes the control aspects of shifting control, speed control and acceleration control; (3) it allows users to instantaneously adjust the rolling speed according to different operation environments (e.g. a low speed for precise reading and a high speed for longer page jumps.) The advantage of the DA method is most prominently demonstrated at larger moving distances. Scrolling tasks using present mouse wheel devices have the following weaknesses: (1) the discontinuity position shift nature limits the efficiency of the rough adjustment stage (travel time); (2) indistinct and non-uniform speed change settings will decrease the stability of aiming tasks; (3) the time required for finger recovery causes unnecessary but mandatory increases in task time.

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