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Grasping and Attached Mode in Human-Computer Interaction in the Study of Mouse Substitution

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Abstract. Some disabilities caused by sensory malfunction, accident, or congenital disorder could cause people difficulty in grasping the computer mouse. A well-known substitute uses an inertial sensor to monitor the body's orientation. This paper evaluates the efficiency and effectiveness of different methods of holding the sensor. There are two modes of holding the sensor, the grasping mode and the attached mode; we also evaluate a mouse as a baseline. The attached mode works by placing the sensor on the back of user's hand. The quantitative and qualitative evaluation procedure is based on ISO/TS 9241 part 411: Ergonomics of human-system interaction standard. The test consists of four levels of difficulty and indicates that the *throughput* and *task completion times* were not statistically different between grasping and attached mode. We also found that grasping mode and attached mode did not show significantly statistical differences in comfort and fatigue based on the questionnaires. The results also suggest that the orientation of the hand used in grasping and attached modes is suitable only for lower-impact computer use.

1. Introduction

This study presents an opportunity to evaluate interaction techniques using an inertial sensor as a pointing device.

1.1. Background and purpose

The human-machine or human-computer interface is defined as humans and computers communicating with each other, including hardware and software. The design of any physical input device has been investigated extensively in terms of ergonomics and human factors [1].

A mouse is an important physical input device in using a computer. However, due to accidents, sensory malfunction, or congenital disorders, some people are unable to grasp the mouse. Therefore, this research evaluates a mouse substitution device and its interaction techniques. This research chose



an orientation sensor as a mouse substitution device. This paper focuses on evaluating the interaction techniques, i.e. the grasping mode and the attached mode. In the grasping mode, the user holds the sensor in their hand, while in the attached mode, the sensor is placed on the back of the user's dominant hand (opisthenar).

1.2. Related work

A variety of researchers have looked at mouse substitution devices. One study used earphones with an accelerometer to control cursor movement based on the movement of the user's head [2]. Other studies have evaluated the accuracy of eye tracking techniques to substitute the mouse [3]. However, substituting mouse use with head or eye movement feels unnatural, while using hand movement is a more natural approach.

The practice of grasping a gyro-based sensor is relatively common. Researchers have evaluated some products that use this technique: Nintendo Wii remote [4], [5]; GyroPoint by Gyration [6]; and RemotePoint [6]. The grasping mode works based on the wrist and forearm movement in the body's tri axial plane. The flexion-extension and radial-ulnar deviation of the wrist represent pitch and yaw, respectively, while the pronation-supination of the forearm movement represents roll. Pitch can range from -38° to 40° , while the range of roll is -28° to 38° , and the range of yaw is -13° to 53° [7, 8].

This study assumes that, in the attached mode, the sensor would be placed on the back of the dominant hand, positioning it quite similarly to the sensor in the grasping mode. Therefore, the range of motion in the grasping mode is identical to that of the attached mode.

Pain and inability to grip can come from many causes, such as: 1) peripheral neuropathy, caused by damaged peripheral nerves; 2) brachial plexus injury, or the disruption of the network of nerves from the spinal chord to the shoulder, arm, and hand; 3) dupuytren's disease, when the fascia of the palm and fingers thickens, then tightens over time; and 4) spinal stenosis, which causes pain, numbness, tingling, and muscle weakness.

Because of these difficulties in grasping, and based on our assumption that the attached mode has the same range of motion as the grasping mode, we would like to evaluate the efficiency of these modes in facilitating the interaction between human and computer.

The procedure used to evaluate physical input devices based on the ergonomics of human-system interactions is described in ISO 9241, which is based on Fitts's law. Inspired by evaluation procedure as in other studies [4, 5, 9, 10], this study compares the performance of grasping and attached modes based on ISO/TS 9241 part 411: evaluation methods for the design of physical input devices.

2. Evaluation of grasping mode and attached mode

2.1. ISO/TS 9241-411

Series 400 in ISO 9241 discusses the physical input device, while part 411 quantitatively and qualitatively evaluates the input device [11]. The quantitative procedures measure the throughput (TP) and the task completion time or movement time (t_m), while the qualitative assessment uses a comfort-rating scale to assess ergonomics. This study focuses on the multi-directional tapping test as illustrated in figure 1a. The target is twenty-five small circles with the diameter arranged according to the level of difficulty.

As shown in figure 1a, the level of difficulty (I_D) was set using d and w , where d is the distance of movement and w is the target width. The formula for I_D is as follows:

$$I_D = \log_2 \frac{d+w}{w} \text{ (bit)} \quad (1)$$

As the tapping coordinate by users spreading around the target's center, therefore the effective value (ID_e) should be used to adjust the accuracy [9, 11]. Then (1) was modified to create (2).

$$ID_e = \log_2 \left(\frac{d}{w_e} + 1 \right) \quad (2)$$

where w_e is the effective target width as $w_e = 4.133 \cdot s_x$

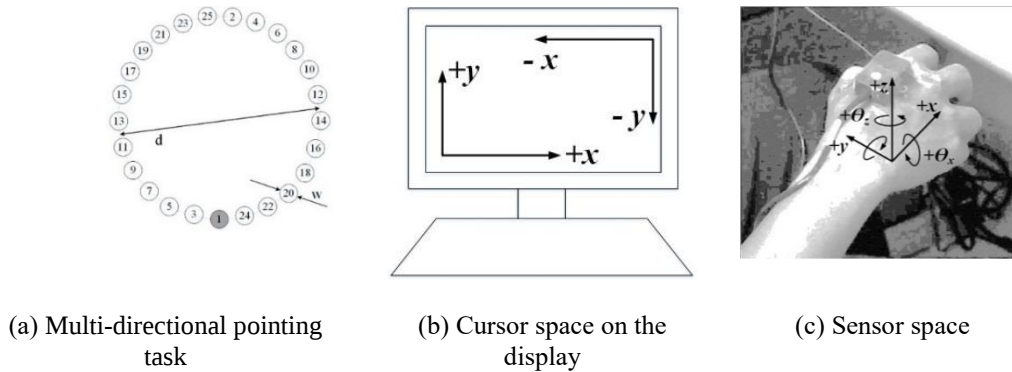


Figure 1. The axes of the display and sensor: (a) Multi-directional pointing task: d = the distance of movement; w = target width; (b) Display axis on the PC monitor and its direction; (c) Orientation axes of the hand movement corresponding to pitch (y-axis), roll (x-axis), and yaw (z-axis).

The value w_e is the effective target width, while s_x is the standard deviation of the coordinates that were clicked compared to the target coordinates. Finally, the throughput (TP) in bits per second (bps) is defined as ID_e divided by movement time (t_m), as in (3).

$$TP = \frac{ID_e}{t_m} \quad (3)$$

2.2. Method

2.2.1. Participants. Twelve male subjects were recruited from alumni and university students who were an average of 25 years old. All participants were right-handed and regular mouse users.

2.2.2. Design. The dependent variables of this experiment are throughput (TP) and movement time (t_m), and the factor is interaction technique on three levels: using a standard mouse, using a grasping mode, and using an attached mode. The grasping and attached modes used an orientation sensor. The standard mouse was used as the baseline. All participants completed tasks consisting of: 1) three levels of interaction techniques; 2) four modes of difficulty (very low/mode1, low/mode 2, medium/mode 3, and high/mode 4); 3) three blocks of experiments; and 4) five trials per block. Therefore, for twelve participants, the number of trials is $12 \times 3 \times 4 \times 3 \times 5$, equaling 2,160.

Each participant conducted questionnaires to assess the comfort and fatigue involved in each factor's level. The comfort-rating scale and rating of perceived exertion (RPE) were adapted from Anec C of ISO/TS 9241- 411.

2.2.3. Apparatus. The experiment was conducted using a Pentium dual core PC, 2.70 GHz, RAM 4096 MB, with a Windows 8.1 operating system, a Microsoft wired keyboard 500, a Microsoft basic optical mouse v2.0, and a 17 inches LG Flatron L177WSB monitor as a display. A three DOF tracking InertiaCube 4TM was used for the grasping and attached mode experiments.

The multi-directional tapping test were conducted using a C# software program developed by the researchers. The software records the movement time, number of errors, and clicked coordinates per target.

2.2.4. Procedure. Each participant was instructed to sit about 50 cm from the display. The position of each test condition is as follows. For the level 1 test, the standard mouse was placed on the computer table as usual. For the level 2 test, the grasping mode, the participant grasped and moved the sensor to emulate the movement of a mouse, changing the cursor on the display accordingly. For the level 3 test, the attached mode, the sensor was attached to the back of the participant's dominant hand, and participant moved his wrist to emulate moving a mouse. The click action was executed using a standard mouse's left button. Each participant grasped the mouse with the non dominant hand to give the click action when the cursor reach the target.

The orientation of wrist substitutes the movement of mouse cursor. The details are as follows: 1) The flexion-extension, which is the rotation angle about y-axis (pitch), mapped the movement of the wrist to vertical cursor movement on the display, as shown in figure 1b.; 2) the radial-ulnar deviation of wrist, which is the rotation angle about z-axis (yaw), was mapped to the horizontal movement of the cursor on the display.

Table 1. The Sensor-Cursor Mapping

Movement	DOF	Sensor space (wrist)	Cursor space (display)
Pitch-Yaw	x		-
	y		-
	z		
	θ_y	+	
	θ_x		
	θ_z	+	

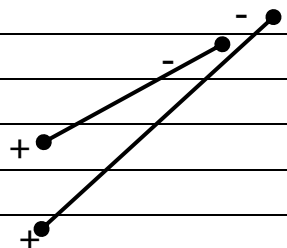


Table 1 illustrates the mapping between the cursor and the display spaces. The rotation about the positive and negative y-axis is the flexion and extension of the wrist, respectively (see figure 1b). Flexion moved the cursor down, while extension moved the cursor up. On the horizontal axis, the wrist's radial deviation in accordance with the positive rotation about the z-axis moved the cursor to the left, or toward the negative x axis of the display. The ulnar deviation of the wrist moved the cursor to the right, or to the positive x axis of the display.

3. Experiment Results

3.1. Throughput and movement time

Throughput is a valid measurement of the speed and accuracy of each task. The bigger the TP is, the more superior the cumulative value of speed and accuracy of a device is. Table 2 summarizes these results, including the error rates.

Table 2. Experiment and qualitative results

Measurement	Interaction technique ^a		
	Mouse	Grasping mode	Attached mode
TP (bps)	5.09 (0.16)	1.62 (0.36)	1.61 (0.41)
t_m (s)	0.87 (0.26)	2.83 (1.40)	2.94 (1.62)
Error rate (%)	3.03	24.51	28.14
Qualitative Assessment	Interaction technique ^b		
	Mouse	Grasping mode	Attached mode
Mean of Comfort	6.6	4.1	3.6
Mean of Fatigue	6.2	4.5	3.6

^a presents in mean (s.d.)

^b in average using 7-point Likert scale; 7 is the best impression

In this experiment, we found that the mouse as a baseline has a TP of 5.09 bps, while the average TP of the grasping and attached modes are 1.62 bps and 1.61 bps, respectively. It is noted that the TP values of the grasping and attached modes are almost the same; both are 68% under the TP of the mouse.

The Shapiro-Wilk normality tests indicate that the TP values of the mouse, grasping mode, and attached mode were normally distributed ($p > .05$). Levene's test of the homogeneity of variances indicates that the variances of categories in the interaction techniques are not equal ($F(2,33) = 4.193$, $p = 0.024$). The assumption of homogeneity is not met. Therefore, the Welch ANOVA was used to understand whether there is a difference in the means of the throughput values between the interaction techniques. The Games-Howell post-hoc test revealed that there are statistically significant differences between the TP values of the mouse and the two other interaction techniques ($p < .0005$). However, there is no statistically significant difference between the TP values of the grasping and attached modes.

Analyzing the movement time (t_m) revealed that the mouse data is not in normal distribution ($p < .05$). The independent-samples Kruskal-Wallis test showed that there were statistically significant differences between categories ($\chi^2(2) = 23.35$, $p = .0005$). The post-hoc Mann Whitney U test concluded that the movement times in grasping mode were not statistically different from those of the attached mode ($U = 72$, $p = 1.0$). However, the t_m in grasping mode is significantly higher than in mouse ($U = .0005$, $p = .0005$), and the attached mode time is also significantly higher than mouse time ($U = .0005$, $p = .0005$).

3.2. Error rate

Error was calculated when the clicked occurred outside of the small target circle (see figure 1a). Error rate was the result of the mean error of all trials for twelve participants. The error rate in each level of difficulty indicates that modes 3 and 4, the medium and high difficulty levels, have a sharp increase in the grasping and attached mode. As also seen in table 2, the mean error rates of the grasping and attached modes are 88% and 89.2%, respectively, both greater than the error rate of the mouse.

3.3. Qualitative results

The qualitative results come from the independent rating scale of each level of the interaction technique. The rating scale consists of seven questions concerning comfort and five questions concerning fatigue. Rated on a 7-point Likert scale in which 7 is the best impression (most comfortable and least fatigued), the average values of comfort and fatigue are described in the table 2.

Table 2 indicates that the comfort of the grasping mode is slightly higher than that of the attached mode, and the fatigue caused by the grasping mode was less than that of the attached mode. However, both the comfort and the fatigue of the grasping mode are not statistically different from that of attached mode ($U = .0005$, $p = .002$ and $U = .0005$, $p = .009$, respectively).

4. Discussion

From the results of throughput as shown in table 2, we found that the TP for the mouse is 5.09 bps. This is in line with other research, in which the mouse's TP ranged from 3.0 to 5.0 bps [6]. This indicates that the methodology and experimental procedure in our study is similar to that of the other research.

Interestingly, although the grasping mode shows higher performance in TP and movement time (t_m), it was revealed that the grasping and attached modes did not show significance differences. Similarly, we found that the levels of comfort and fatigue of both the grasping and attached modes were not statistically different. This main result of our study builds upon on previous empirical research in human-computer interaction as in [12, 13].

In order to discover which levels of difficulty (I_D) had a significant impact on TP and t_m , we tested each level of difficulty, i.e. mode 1, mode 2, mode 3, and mode 4. First, the focus is on mode 3 (medium level of difficulty) versus mode 4 (high level of difficulty): 1) The TP of grasping mode was significantly different between the two levels of difficulty ($t(2) = 11.20$, $p = .008$). The t_m was also significantly different ($t(2) = -9.55$, $p = .003$); 2). The TP of attached mode has a significance difference on both levels of difficulty ($t(2) = 23.88$, $p = .002$), and t_m was also significantly different ($t(2) = -6.97$, $p = .020$).

Second, we also found that the TP and t_m values of mode 2 (low level of difficulty) are significantly different from those of mode 3. However, there is no statistically significant difference between the TP and t_m values of mode 1 (very low level of difficulty) and those of mode 2. These findings may suggest that both the grasping and attached modes are suitable for tasks with very low and low levels of difficulty.

5. Conclusion

This study evaluates two human-computer interaction techniques that substitute mouse movement. The research used two types of hand orientation: grasping the sensor, and attaching the sensor to the back of the hand. Results revealed that the differences in throughput and task completion time of grasping and attached mode are not statistically significant. The study also recommends the use of orientation sensors in grasping and attached modes for low difficulty tapping tasks.

The study did have some limitations. This study focuses on the pitch-yaw movement of the wrist (flexion-extension and radial-ulnar deviation) as a substitute for the mouse cursor movement. The results would likely be different using other movements, such as pitch-roll (flexion-extension and pronation-supination). Additionally, the substitute for a mouse's left-click was executed by clicking a button on a standard mouse placed in the participant's non-dominant hand. In some situations, a user may not be able to move their fingers, meaning the experimental procedure in this study might need some adjustment.

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