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Effects of Clutching Mechanism on Remote Object Manipulation Tasks

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Abstract

Remote object manipulation in practice is often an iterative process that needs clutching. However, while many interaction techniques have been designed for manipulating remote objects, clutching mechanism is often an important but overlooked aspect in manipulation tasks. In this paper, we evaluate the effects of clutching mechanism on remote object manipulation tasks, which compares two clutching mechanisms under various tasks settings. The results suggested that an efficient clutching mechanism can effectively improve the usability in remote object manipulation tasks.

Index Terms: Human-centered computing—Interaction design—Empirical studies in interaction design; Human-centered computing—Human computer interaction (HCI)—Interaction techniques—Pointing

1 Introduction

Remote objects are much harder to be manipulated compared with in-reach objects, since users cannot directly interact with out-of-reach objects by grasping. Despite that there are many interaction techniques designed to address the issue of remote object manipulation, in practice, many remote object manipulation tasks cannot be finished in one go. In fact, manipulating a remote object is often an iterative process, where users may need to release an object and then reselect the same object multiple times until satisfied. Thus, clutching mechanism is particularly important for remote object manipulation tasks, since manipulation is often preceded by selection, and selecting out-of-reach objects has been reported as one of the major problems in 3D user interfaces. Hence, considering the fundamental nature of manipulation tasks, it is vital to study how clutching mechanism can affect manipulation tasks in virtual environments, so that the performance for manipulating remote objects can be further improved.

2 Related Work

Clutching issues in user interfaces are non-trivial, since most usability problems and ergonomic difficulties can arise due to poor clutching design. Many studies have shown that clutching can have a negative effect on user performance in various tasks, such as pointing tasks, manipulation tasks that require rotation, etc. Based on Buxton's three-state model of graphical input [2], Wozniak et al. introduced a design procedure for determining optimal clutching mechanisms, which is a four-stage diagram explaining the phenomenon [3]. While studies have demonstrated that clutching issues can be mitigated by designing proper interaction techniques, clutching issues of manipulation tasks in 3D user interfaces have yet to be well explored, which will be our focus in this paper.

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3 Clutching Mechanism for Remote Object Manipulation

We first analyze state transitions in remote object manipulation tasks based on Buxton's three-state model [2]. Since users always need to hover (to position a cursor over something without selecting it) an object first before selecting it, we further divide the State 1 in Buxton's model into two sub-states to present whether an object is being hovered (see Fig.1a). In some scenarios, the state could switch from State 2 to State 1a directly when releasing the object due to the offset created between the cursor and the target during a manipulation process. In these cases, if the user needs to refine the manipulation, hovering is required to reselect the same object. Since hovering can be a time-consuming operation compared with other operations like button press, considerable time could be wasted for reselecting the same target, making the workflow in iterative manipulation inefficient.

To address the issue in the clutching mechanism above (thereafter referred to as Normal Clutching), we propose a new clutching mechanism: Easy Clutching. Specifically, a "State 3" is introduced in this clutching mechanism, which allows Easy Clutching retain the selection state of an object rather than release the object immediately when a user releases the button. Users can keep manipulating the object without the need to select it again. To release the selected object, users can simply press a secondary button to end the manipulation process (see Fig.1b).

4 User Study

In this study, our goal was to investigate how clutching mechanism can impact user performance and user experience under various remote object manipulation task settings (see Fig.1c). Based on the design of our study, we formulated two main hypotheses:

H1: *Easy Clutching will have shorter completion times than Normal Clutching in remote object manipulation tasks.*

H2: *Easy Clutching will have lower overall workload than Normal Clutching in remote object manipulation tasks.*

In the experiment, *clutching mechanism*, *task type*, *task difficulty* and *target distance* were varied as independent variables. For *clutching mechanism*, there were two levels: Normal Clutching (NC) and Easy Clutching (EC). For *task type*, there were three levels: 3-DOF Translation (T), 3-DOF Rotation (R) and 6-DOF (T+R). For *task difficulty*, there were two levels: Easy and Hard (details are listed in Table 1). For *target distance*, there were two levels: Near (2m) and Far (8m). For dependent variables, we collected completion time, clutching time and workload using NASA-TLX. The experiment followed a $2 \times 3 \times 2 \times 2$ within-subjects design, which resulted in 24 conditions in total. The order effects were counterbalanced by using a balanced Latin square design.

An HTC Vive VR system (2160 x 1200 resolution, 90 Hz refresh rate, 110º field of view) was used in the user study. Considering that many interaction techniques may benefit from clutching mechanism, we chose HOMER as a representative to evaluate the effects of clutching mechanism, which combines ray-casting selection and hand-centered manipulation [1]. At the beginning of each trial, a user-controlled object (a tetrahedron with a edge length of 0.7m)

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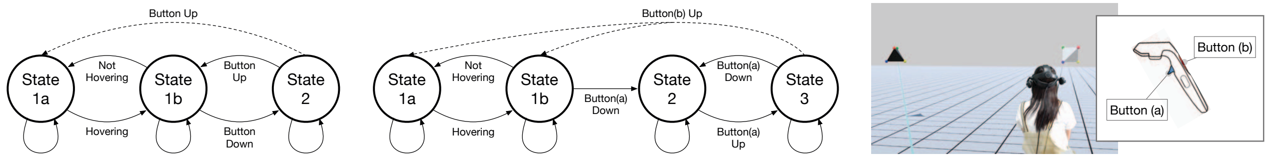
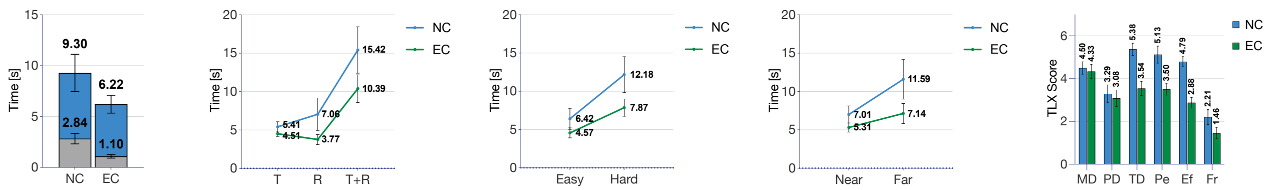


(a) Normal Clutching (b) Easy Clutching (c) Task setup and button configuration

Figure 1: Clutching mechanism in remote object manipulation tasks.



(a) (b) (c) (d) (e)

Figure 2: (a) The completion time (the total bar) and clutching time (the gray section) for Normal Clutching (NC) and Easy Clutching (EC); The interaction effects on completion time between (b) clutching mechanism and task type, (c) clutching mechanism and task difficulty, (d) clutching mechanism and target distance; (e) The subscales of NASA-TLX scores, with 95% confidence intervals.

and a target were placed in a virtual environment based on the predefined parameters in Table 1. Participants were told to move and/or rotate an object to align it with a target using their dominant hand as accurate as they could (see Fig.1c). For each trial, when the threshold was met, the trial was finished, and the results were recorded by the system. The next trial could start automatically after 1-second pause, until all the trials were completed.

The experiments began with a training session, where an experimenter gave an explanation of the device and tasks and then the subjects were given 24 trials to practice in each condition to get familiar with the system before the assessment session. In the assessment session, a participant needed to finish 5 trials for each condition. After all the tasks were finished, the participants needed to complete a post-test questionnaire which collected their demographic information and subjective evaluation for two clutching mechanism. The experiment for each participant lasted for approximately 40 minutes.

Table 1: Predefined parameters in the experiment (A = initial distance mismatch; W = distance threshold; α = initial angle mismatch; ω = angle threshold).

	T		R		T+R	
	Easy	Hard	Easy	Hard	Easy	Hard
A (m)	3.2	12.8	0	0	3.2	12.8
W (m)	0.05	0.05	-	-	0.05	0.05
α (°)	0	0	32	128	32	128
ω (°)	-	-	8	8	8	8

5 Results

24 unpaid volunteer subjects (17 males and 7 females) participated in the experiment, whose age ranged from 22 to 30 years (M = 24.17, SD = 1.79). A repeated-measures ANOVA showed that clutching mechanism significantly affected completion time ($F_{(1,23)} = 31.331, p < 0.001, \eta_p^2 = 0.577$) and clutching time ($F_{(1,23)} = 73.843, p < 0.001, \eta_p^2 = 0.763$), which confirmed hypothesis **H1** (see Fig.2a). Significant interaction effects on completion time were detected between clutching mechanism and task type ($F_{(2,43)} = 14.053, p < 0.001, \eta_p^2 = 0.379$; see Fig.2b), clutching mechanism and task difficulty ($F_{(1,23)} = 35.281, p < 0.001, \eta_p^2 = 0.605$; see Fig.2c) and clutching mechanism and target distance ($F_{(1,23)} = 18.563, p < 0.001, \eta_p^2 = 0.447$; see Fig.2d). The results of NASA-TLX scores showed that Easy Clutching had significantly lower overall workload than Normal Clutching ($t_{(23)} = 19.395$, $p < 0.001$), which confirmed hypothesis **H2** (see Fig.2e).

6 Discussion

Taking HOMER as a representative interaction technique, this paper demonstrated that clutching mechanism can play a vital role in remote object manipulation tasks, as Easy Clutching significantly improved completion time compared with Normal Clutching. In particular, the significant interaction effects between various factors and clutching mechanism on completion time revealed that the benefits of Easy Clutching can be more pronounced in more challenging manipulation tasks. Furthermore, NASA-TLX scores showed that Easy Clutching had significantly lower workload than Normal Clutching, which suggested that Easy Clutching can provide better user experience in manipulation tasks.

Our work is a starting point for understanding how clutching mechanism can affect remote object manipulation tasks. While our study showed the effectiveness of Easy Clutching, it is likely that there are other optimal clutching mechanisms can be designed with the help of Buxton's model. In addition, as we only evaluated HOMER in our experiment as a representative interaction technique, further evaluations of other interaction techniques under different scenarios (e.g., in dense environments, using selection-only tasks) are necessary to better understand clutching mechanism.

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