Comparing Single- and Two-Handed 3D Input for a 3D Object Assembly Task

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ABSTRACT
In this paper, we describe the design and evaluation of an interface for 3D object assembly that can be operated with either one or two hands. The justification for applying two-handed input is evaluated by studying the results of an experiment in which the performance of single- and two-handed operation are compared. Performance is established using the time needed to complete a 3D object assembly task. Experimental data show that the two-handed interface takes more time to learn but eventually leads to faster completion times within a one hour period. It is therefore concluded that the choice for two-handed input is appropriate.

Keywords
3-D interfaces, Input Devices, Two-handed Input

INTRODUCTION
The interface discussed here is part of an experimental modeling system that is being developed for supporting geometric modeling in the conceptual design phase. Computer systems developed for this purpose, should be highly intuitive and responsive so that they do not interfere with the designer's creativity and train of thought. The interface techniques of the assembly component are developed for this purpose. Two aspects make it stand out from standard CAD tools. It utilizes both two-handed input and "spatial input".

The term spatial input was introduced by Hinckley [2] as a sub-category of the more general term "3D interfaces". It "refers to interfaces based upon free-space 3D input technologies such as camera based or magnetic trackers, as opposed to desktop devices such as the mouse or the Spaceball". Examples of systems with spatial input include the 3-Draw sketch based design tool [6], the surface design tool THRED [7] and Hinckley's props interface for neurological visualization [3]. Apart from these specialized applications previous work on spatial input includes formal user studies on topics like target acquisition [8] and the selection of input devices [4].

Two-handed input is becoming an accredited technique for interface designers to create efficient, intuitive and rich interfaces, both in the 2D and 3D domain. Good results are found especially with interfaces that employ "asymmetric dependent" task assignments [1], referring to assignments that make dominant hand actions depend on non-dominant hand actions.

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2D interfaces like the ToolGlass [5] have shown that users are quick to transfer their everyday skills for manipulating tools to the computer. This phenomenon is also found in 3D interfaces and, here, two-handed input can contribute to an increased 3D space perception too [2].

INTERFACE DESIGN
The input device developed for the interface is called the "Frog" and is shown in Figure 1. The frog is designed to be held with the fingers, intentionally avoiding the whole-hand for reasons of comfort and efficiency [8]. Inside the frog is a six degrees of freedom, magnetic, tracker that measures the Frog's location and orientation. The top view of the Frog shows two buttons, used to select objects and to clutch. The Frog's design is symmetrical and is used by both the left and the right hand.

Figure 1, The Frog, side view and top view.

Figure 2 presents the screen of the test program. A 3D cursor is visible in the middle of the picture. Three lines connect the center of the cursor to three planes that represent the boundaries of a cubical workspace. The cursor and the objects in the scene are confined to the interior of the workspace.

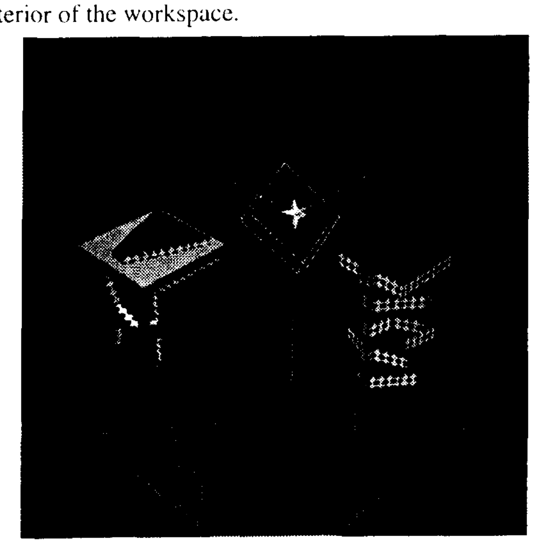

Figure 2, Screen shot from test program.

The cursor is operated with the frog held in the dominant hand. Objects are selected by pressing the selection button on the frog while the cursor is over a visible part, a variation on the "ray casting" selection method [2]. Groups of objects can be selected by dragging an outline box around their visual location on the screen. The current selection is indicated by the presence of a bounding box. The selected object(s) can be moved and rotated by holding the selection button down. In Figure 2 the cursor has selected the triangular object and is dragging it. Pressing the clutch button on the frog will activate the clutch mode. In this mode the frog can be moved without affecting the cursor, enabling the user to return his or her hand to a comfortable position.

The frog held with the non-dominant hand is used to position and orient objects not being dragged by the dominant hand. The two buttons on this frog are both used to clutch, pressing either button will activate the link between frog and objects. The non-dominant hand can assist the selection process by bringing the object close to the cursor. In case an object is being dragged to be placed upon a target object, the non-dominant hand can move and orient the target object, such that it facilitates the placement.

EXPERIMENT

Two conditions, one- and two-handed operation, were used in the experiment. The task consisted of placing the six objects depicted in Figure 2 onto the corresponding shapes on the sides of the cube. Objects had to be assembled in the order they were presented. When the relative position and orientation of the cube and the object met the match criteria they were joined and a "click" sound was played. Subjects were instructed to complete the assembly as quickly as possible.

A within-subjects design was chosen for the experiment. Each subject was tested with both conditions on the same day. The 24 volunteer subjects that entered the experiment were paid students, 12 male and 12 female. The order of the conditions was counter-balanced and both groups consisted of six male and six female subjects. The experiment started with a 20 minutes instruction including one warm-up trial. Then a first block of six trials was offered with a randomized distribution of shapes over the sides of the cube for each trial. Before the start of the next condition, subjects were offered a short break and another warm-up trial. Then the second block of six trials was issued.

Figure 3 shows the mean and standard errors of the completion times for different conditions and blocks. The difference found between the mean values found after the first half of the experiment is not significant. However, by calculating the t ratio we find that the difference found between the bars on the right is significant: $t = 2.439$, $p < 0.05$. These bars represent the mean values of the completion times of the second half of the experiment only. The two-handed condition performs 17.5% faster than the one-handed condition. The Order × Hands interaction is not significant, which implies that the skill transfer from the one- to the two-handed condition did not significantly differ from that of the skill transfer from the two- to the one-handed condition.

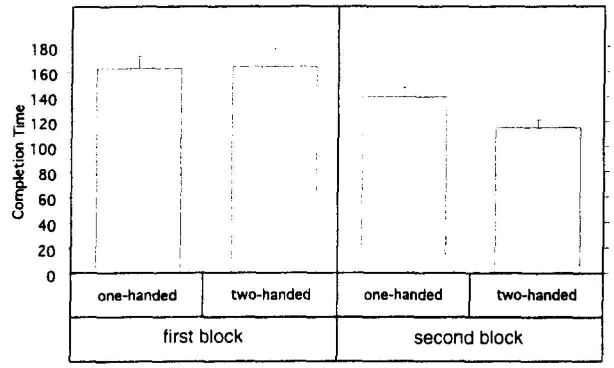

Figure 3, Mean and standard error of completion times for one- and two handed operation.

CONCLUSIONS

The data from the experiment shows that two-handed operation leads to faster completion times within the context of the interface we have designed for object assembly. This is in accordance with results found in previous two-handed interfaces. A difference of 17.5% is found in the second half of the experiment, after about 40 minutes of experience. Follow-up research will study the rest of the experimental data, analyzing two-handed operation in detail.

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