3D Modelling Is Not for WIMPs

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Abstract

This study compares a traditional 3D WIMP (Window Icon Menu Pointer) modeller to a prototype of a novel system with a 6DOF haptic feedback device, stereovision and a co-located display, both in quantitative and qualitative terms. The novel system was conceived to overcome limitations of traditional interaction techniques and devices when dealing with three-dimensions. Experimental results confirm the fundamental role of spatial input for 3D modelling and the significant contribution of haptics and stereovision to qualitative and quantitative performance. A review of relevant research and motivations for the study is presented along with a discussion of main outcomes.

1 Introduction

Although research highlights shortcomings of WIMP systems for 3D tasks, popular 3D modellers based on those systems, such as 3D studio MAX,™[1] are widespread in Design practice. However commercially available 3D modellers tend to overcome constraints imposed by the physical set up of the workstation by using advanced software functions. This introduces the disadvantage of a steep learning curve, but also promises efficient performance once the software is mastered; thus expert users might find such systems satisfactory and efficient.
However, 6DOF haptic interfaces may be greatly more efficient and usable.

2 Related Research

It has been argued that traditional WIMP systems are inadequate for effective 3D modelling due to a mismatch between DOF (Degrees of Freedom) required for the task and afforded by the input device. Manipulation of 3D objects exhibits a parallel structure of translation and orientation that, if transformed into a serial structure, may significantly increase the total task completion time (Wang Y. and MacKenzie C L., Summers V. A. and Booth K. S., 1998). Interacting with a virtual model for a positioning task means defining separate parameters, expressing orientation and position components for X, Y and Z axes (Butterworth J., Davidson A., Hench S. and Marc T., 1992), which must be input separately with a mouse device. Lack of depth cues, typical of traditional 2D-displays, can also hinder 3D interaction: using a 6DOF Polhemus device with a 2D display makes it difficult to select a target (Badler, N. I., Manoochehri, K. H., Baraff, D., 1986). Other research shows that a stereoscopic display in a positioning task with a 6 D.O.F. input device reduced error rate by 60% (Beaten R.J., DeHoff R.J., Weiman, N. and Hildebrandt, W., 1987). Overall, Jacobs' statement that the structure of the perceptual space of an interaction task should

[1]3ds max is a registered trademark. Discreet is a division of Autodesk, Inc.

mirror that of the control space of its input device (Jacob, R.J.K. & Sibert L.E., 1992) summarizes the above issues well, since the effectiveness of an input device is relative to the task rather than being absolute. In turn, different devices "suggest" specific cognitive strategies, influencing how users "think" about a task (Hinckley K., Paush R., Proffitt D., 1997). Research in psychology (Parsons L., 1995) and in HCI shows that experiencing 3D space helps the user to understand it (Hinckley, K., 1996): this should be taken into account in implementing novel systems for 3D, since cognitive activities are fundamental in HCI models. A system providing coherent depth cues, spatial input and a more "natural" environment for spatial interaction could be regarded as desirable for 3D interaction. However practical implementation presents many drawbacks, arising from limitations in available technologies. Exploitation of physical devices for interaction with computers such as tangible interfaces and physical props works towards restoring a more natural interaction. However this can in turn limit the flexibility offered by the digital medium. If "natural" interaction was to be achieved via software, this could be preferable, although it might impose a cognitive load on the user, as software widgets must be "understood" (Hinckley, K., 1996). Haptic displays, such as force feedback devices with 6DOF, could represent a valuable compromise, being both "programmable" and affording the use of our natural skills in manipulation. It has been shown that haptic force-feedback improved performance in a peg-in-hole task (Massimino, M. J., & Sheridan, T. B., 1994) and that use of haptic widgets, such as "gravity wells" improved precision in a 3D-targeting task. (Wall S. A., Paynter K., Shillito A.M., Wright M., Scali S., 2002). Force feedback devices could be further enhanced through co-located displays particularly in situations requiring a 3D rotation (Ware C. & Rose J., 1999).
These considerations led us to devise a study to test if a novel system with the above specifications would outperform a WIMP system running 3D studio MAX™[2].

3 Hypothesis

Independent variables to be tested on a macro-level are the above two systems and the provision of haptics, stereovision and spatial input in related subsystems. Dependant variables are performance and user's perception of workload and of system's usability in completing a 3D Combining task. Two systems were compared: (a) a PC with 2D-display, 2DOF input device, with standard 3D modelling software and (b) a workstation with 6DOF spatial input device which selectively affords stereo vision and haptic feedback, running a prototype 3D modelling software, with an optional snap alignment tool. Subsystems of (b) were tested against (a), and against each other in order to clarify contribution of single elements of (b) to the overall performance. This produced a total of seven conditions:

I. WIMP system running 3Dstudio MAX
II. 6DOF input device, stereovision, haptic feedback, with snap tool
III. 6DOF input device, stereovision, haptic feedback, with no snap tool
IV. 6DOF input device, no stereovision, haptic feedback, with snap tool
V. 6DOF input device, no stereovision, haptic feedback, with no snap tool
VI. 6DOF input device, stereovision, no haptic feedback, with no snap tool
VII. 6DOF input device, no stereovision, no haptic feedback, with no snap tool

In the context of related work we hypothesized the following:

i. System (b) and subsets will lead to a better performance compared to (a)
ii. System (b) and subsets will lead to lower workload scores compared to (a)
iii. System (b) and subsets will lead to a higher usability compared to (a)
iv. A correlation will be found between performance, usability and workload perception.

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[2] According to on-line pools, 3D studio Max™ is one of the most used 3D modeling software. (e.g. http://www.renderology.com/polls/default.asp). It also offers a solid scripting utility that has been exploited.

v. The spatial input device will be the most important contributor to the increase in performance (due to affordance of 3D rotation / translation and better cognitive fit to 3D).
vi. Haptics and stereovision will decrease completion times and perception of workload.

4 Experimental Design and Procedure

The experimental method is a "within subjects" design. A total of 12 subjects were recruited among expert users of 3Dstudio Max™. A WIMP (Window Icon Menu Pointer) system running 3D Studio Max™[3] (a) and a system equipped with a Reachin Developer Display[4], a PHANToM™[5] haptic force feedback stylus device, a co-located display and a non-dominant hand input device, Magellan Space Mouse ®[6], (b) were utilized.

An equivalent task was performed on both workstations. Task entailed placing 4 different geometric elements, randomly scattered and orientated in space, against non-movable "target" surfaces, recognisable by matching dimensions and colors, also placed in various positions and random orientations.

As users were asked to repeat the given task three times under the seven different experimental conditions (I to VII)[7], random orientation and positioning of target surfaces and shapes were predetermined for each repetition. The presentation order of the different conditions and repetitions was randomised to neutralise any learning effect or other relevant interactions. Subjects were allowed to adopt any preferred strategy within the system's limitations, and time limits were not imposed, although accuracy and completion times were measured to evaluate performance[8]. Qualitative data was gathered using a computer version of the TLX [9] Task Load Index test (NASA) and in a SUS (System Usability Scale, Brook, J. 1996) questionnaire. Qualitative data was gathered after each subject had completed the three trials of each condition (I-VII). Instructions for completing the questionnaires and operating the Reachin's system were given before each experimental session. Users were given time to familiarise themselves with the task under the various conditions.

5 Results and Discussion

Data analysis confirmed the main hypothesized outcome as stated in (i). Figure 1 summarizes data for completion times, used as a measure of performance: a striking difference was found between condition I, which tested system (a), and all other conditions. (e.g. condition II against I: $F(1,70) = 106.7671$, $p<0.01$). Significant discrepancies in performance held true with no regard as to whether or not haptics and stereovision were used. (VII against I: $F(1,70) = 87.95473$, $p<0.01$). This is in agreement with hypothesis (v), as the 6DOF device affording spatial input produced the most significant decrease in completion times. However, performance increased significantly when graphic stereo cues and haptic feedback were provided in addition to the spatial input, in agreement with hypothesis (vi) (VII against III: $F(1,70) = 4.833404$, $p<0.05$). Times dropped further under condition II (stereo, haptics, and snap tool) and this was found to be statistically

[3] Wide variability in data obtained from 3D studio MAX probably indicates a variation in subjects' expertise.
[4] http://www.reachin.se/products/reachindisplay/ (Retrieved February 21, 2003)
[5] http://www.sensable.com/products/phantom_ghost/phantom.asp (Retrieved February 21, 2003)
[6] The Space Mouse affords 3D rotation. This function was not enabled in this study, in order to maintain a coherent equivalence between systems (a) and (b) and to avoid introducing additional variables.
[7] Under all conditions which included haptic feedback (I, II, III) this was provided in the form of a force feedback activated by the point of the stylus hitting a target surface.
[8] Each user clicked a button to start and end the task. Precision results will be omitted in this paper.
[9] The NASA Human Performance Research group defines six different factors for workload (mental demand, physical demand, time pressure, effort expended, performance and experienced frustration), measured through the TLX index tool. Elements are rated, weighted with pair-wise comparisons, and then combined.

significant (condition II against III: F (1,70) = 55.58223, p<0.01). Although the sole use of haptics or stereovision failed to reach significance in the increase of performance over spatial input alone,[10] haptics provision did reach significance when ANOVA tests where repeated excluding one of the subjects, whose measures were extreme outliers. Other results did not vary.

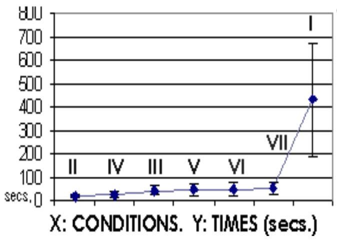

Figure 1

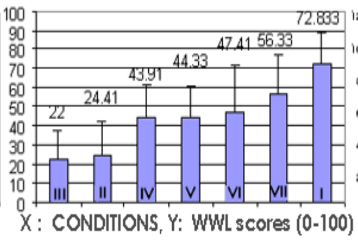

Figure 2

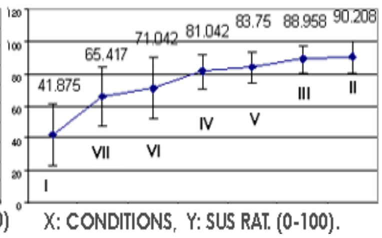

Figure 3

5.1 Perceived Workload

Paired T tests were applied to WWL (weighted workload) scores,[11] which are summarized in fig. 2. Lowest perceived workload (mean: 22/100) was obtained when stereo and haptics without the snap tool were used to complete the task (condition III). Highest WWL score was attributed to the WIMP system running 3D MAX (condition I, mean: 72.83333/100). Overall results also confirm hypothesis (ii), with all WWL scores attributed to system (b) and subsystems significantly lower than whose attributed to system (a)

WWL scores for all conditions where haptics was provided exhibited lower workload rates than all other conditions; this suggests further investigations to better understand effect of haptics in lowering specific elements of workload.

Introduction of the snap tool failed to decrease WWL scores significantly. Perceived workload under condition V (haptics and spatial input) and in condition VI (stereo and spatial input) was lower than in condition VII (spatial input only), although results failed to reach significance in this latter case (condition VI against VII). These findings partially confirm hypothesis (vi).

5.2 System Usability Ratings

Paired T tests were also carried out on SUS ratings, whose mean values and standard deviations are shown in fig. 3. Results strengthen findings obtained from previous analysis on Workload Scores. Condition I (3D studio Max) was rated as the less usable system (41.875/100), followed by condition VII (spatial input). Condition II was perceived as the most usable (90.208/100), whereas the greatest significant gap between ratings was found between condition I and VII (T_{11}= -3.61654, p= 0.002025). Hypothesis (iii) is thus confirmed, since the less usable of the (b) subsystems is significantly more usable than system (a). Again, a significant increase in usability (T_{11}= 4.147522, p= 0.000812) was found between the haptics and spatial input condition (V), compared to spatial input alone (VII). Stereovision (V) failed to determine a significant increase in the perceived usability of the system compared to condition VII (spatial input), although it was rated as more usable. All conditions exhibiting haptic feedback were significantly more usable than other conditions (e.g. condition VI against IV: T_{11}= -2.48504, p=0.015151)

The latter is in agreement with WWL results, which exhibit a strong negative correlation to the SUS ratings, accordingly to the Spearman's ranked correlation coefficient (s =-0.76122084,

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[10] (condition V: F (1,70) = 2.834078, p>0.05; condition VI:F(1,70) = 0.295738, p>0.05)

[11] III, II : T_{11}= -0.50769, P= 0.310846612209752 - II, IV: T_{11} =3.03782, P= 0.005645 -IV,V: T_{11}= -0.12101, P= 0.452932 - V,VI: T_{11}= -0.38631, P= 0.353317 - VI ,VII: T_{11}= -1.23036, P= 0.122113 - VII, I: T_{11}= -1.94813 P= 0.038682 - V, VII: T_{11}= -2.2532 P= 0.022816

p=4.31264E-17). Significant negative correlation was also found between SUS ratings and time measures (s = -0.2205, p=0.043851), thus validating hypothesis (iv). However, the positive correlation found between time measures and perceived workload failed to reach significance (s=0.153915, p=0.162154).

6 Concluding Remarks

The study highlights the fundamental role of spatial input for 3D tasks, suggesting that its use could greatly improve 3D modelling systems. Stereovision and Haptics seem also to ease operating within three dimensions. Haptics seems beneficial in lowering perception of workload and increasing usability, while interface widgets such as the tested snap tool could contribute to lower completion times. Further investigations should clarify related issues in greater depth.
Cautious interpretation of these clear results rests mainly with the issue of systems' equivalence.

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