The Effect of Haptic Feedback and Stereo Graphics in a 3D Target Acquisition Task

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Abstract

Interaction in three dimensional virtual environments is difficult, often resulting in physical or mental fatigue. Haptic interfaces have previously been employed with 2D and 2.5D desktop metaphors in order to improve targeting performance. This paper extends the principle to a 3D environment targeting task. Subjects completed a targeting task with and without haptic feedback, in the form of "virtual magnets" that physically attract the user towards targets in the environment, and with and without the provision of stereo depth cues via a stereo emitter and shutter glasses. It was found that the virtual magnets improved subjects accuracy, but did not improve the time taken to reach the target. Stereo cues improved both the subjects' spatial accuracy, and significantly improved the temporal measure of performance.

1. Introduction

Many of the undesirable traits in today's CAD packages arise due to the difficulty of visualising and developing three dimensional models with 2D interface devices, such as the mouse and the monitor. For example, multiple 2D view points are often used, which can be confusing to novice users. These viewpoints and the user's designs are often manipulated using a bewildering series of icons, buttons and nested menus crammed with technical language. Of course, taking time to learn how to operate a complex CAD package can reap great rewards in terms of the high quality rendering of the resultant model. Often, though, as is the case in the early phases of the design process, a designer or artist will often require drafting of a number of partially complete, rough designs. In this case a high degree of functionality and accuracy is not required, and traditional CAD type interfaces can act as a barrier to the creative thought process, as the user is constantly disrupted by the subtleties of the interface.

This phase of design is normally accomplished using conventional pen and paper sketching. However, a digital approach offers many potential advantages, such as the transferability of designs through electronic communication, recording a history of actions and subsequently being able to "undo" them, reproducibility (easy to make and distribute many copies), portability between platforms (the opportunity to directly use successful designs in a later stage of the process by importing in to other CAD packages) and the unique ability to work, think and draw in 3D. If "a picture is worth a thousand words", a 3D model is worth many times more pictures, as it can be inspected and manipulated from many view points.

Previous examples of 3D modelling systems using 3D input devices have proven to be too unconstrained for accurate guiding and maintenance of position [5]. Mental and physical fatigue are both common in tasks that require true 3D interaction [6], providing a barrier to the externalisation of a designers creative solutions. While the humble pencil can often provide an ideal medium by which to record ideas and sketch, there are obvious benefits to transferring the process of conceptualisation to a digital medium. For example, a computer allows rapid portability of designs via electronic communication, can allowing shrinking, magnification and copying of designs, can store a history of user actions for future reference and also facilitates group working over large distances via the internet.

We believe that haptic interface devices offer a means to interact with 3D data in an intuitive manner, thus allowing the creative freedom that the designer craves in the digital medium. Not only are many examples of devices genuine 3D interfaces, they can provide force cues to aid the operator in the difficult task of visualising and thinking in 3D space. In contrast to conventional teleoperation or simulation tasks, haptic force cues can also include non-physically based force cues that would be difficult to realise in the real world [10]. It is important, however, to achieve a suitable level of haptic assistance, without constraining the user too much. At either extreme, goals are difficult to achieve due to problems of control or inflexibility [13].

This paper describes a study concerning the role of non-physically based, haptic "virtual magnets" in a 3D targeting task. The virtual magnets (also referred to in the literature as "Gravity wells" [11]) create a spring force (that is, proportional to distance) attracting the user to a pre-specified point in the workspace within a certain area of effect. They have previously been shown to be very successful in aiding target acquisition in 2.5D desktop metaphors [11]. In a 2.5D environment, a standard 2D desktop is interacted with via an interface device with 3 or more degrees of freedom (DOF), such as a PHANToM haptic interface.

We hypothesise that by extending the principle to a 3 dimensional environment, haptic feedback can be used to help a user overcome problems with comprehension of 3D space and targeting tasks. We also consider the importance of providing 3D visual feedback using a stereo emitter and shutter glasses, on the effect of user performance.

An experimental procedure is described for determining the effect of the haptic magnets and 3D stereo cues, employing two measures of performance, temporal and spatial.

2. Haptic Feedback for Human Computer Interaction

Using tactile and force feedback to aid human computer interaction has been considered previously. Prior to the widespread availability of force feedback devices, researchers experimented with augmenting the standard mouse with mixed results (e.g. [1]). With the growth of popularity in 3D haptic force feedback interfaces, research has turned to finding effective ways of employing force cues to aid interactions. In particular, applications are common that seek to assist the visually impaired (e.g. [17]) or the motion impaired (e.g. [8]).

Results of Wall and Harwin [14] show that use of force feedback with a 2D graphical display of a 3D environment can improve performance in a Fitts' Law tapping test. Similarly, Arsenault and Ware [2] adopted a reciprocal tapping test methodology in order to investigate the effect of provision of haptic cues with a co-located and head tracked stereo display. The effects of providing force feedback and head tracking was highly significant in reducing target acquisition times. Force feedback also reduced the number of errors that subjects made, and therefore gave an even greater increase in task performance. Both the Wall and Harwin and Arsenault and Ware studies comment on the effect of force feedback allowing the user to 'bounce' between the targets during the tapping test, which facilitates faster acquisition times.

Attempts to enhance 2.5D desktop metaphors have met with limited success. Miller and Zeleznik [9] outline several haptic enhancements for an X Window desktop, though their study was mainly concerned with implementation issues rather than user performance. Oakley et al. [11] showed that errors can be significantly reduced by providing appropriate force feedback, but users' task completion time was unaffected. Results were mixed, in that some haptic effects, such as texturing surfaces, were felt to be disruptive. The most successful augmentation was in the form of a gravity well that attracted the user to targets. We concur with the authors of the study that formal, objective analysis of attempts at haptic augmentation is necessary in order to preclude the eventuality that haptics becomes regarded somewhat as a gimmick, with arbitrary application and disruptive results.

It is in the area of 3D interaction where we may see most benefits from currently available haptic interface technology. Haptics has been employed previously in 3D interaction, adopting "widgets" such as constraining spheres, surfaces and ridges, and more physically grounded effects such as push buttons and viscous switches. However, conclusions are difficult to draw as evaluation was mostly casual and conjectural [10].

3. Co-location, Stereo Vision and Motion Parallax Cues

Several investigations describe the effect of virtual reality graphics techniques on performance in targeting tasks in 3D environments.

"Co-location" is a term used to describe a haptic and visual display which is calibrated such that the visual and haptic co-ordinate systems are coincident. That is, the user can visually perceive an object in the same position in space as the haptic simulation. An example of a co-located display is the Reachin System (www.reachin.se).

Although results would seem to suggest that a co-located display offers no significant advantage to that of a traditional interface held to one side of the body in a translational positioning task [7], Ware and Rose [16] noted that co-location of the hand and virtual workspace improved performance in tasks involving object rotation. It should, however, be noted, that the study by Graham & Mackenzie [7] was 2D and presented no visual information regarding height. One possible problem for co-located displays is a mismatch between the visual and haptic cues that are received due to inaccurate calibration. However, several studies have shown that adaptation to small lateral displacements in the mismatch is rapid and of little consequence to performance. Bouguila et al. [3] present results that suggest that haptic feedback can help to overcome instabilities in subject's depth perception. This has obvious implications for task performance and target acquisition.

Co-located displays are often employed simultaneously with stereo glasses to provide 3D perspective on the visual feedback. Separate images are generated and sent to each of the user's eyes, thus simulating true stereo vision of 3D objects. A further potentially useful tactic is to employ some method of generating motion parallax cues, which arise from a rotation of the 3D scene being viewed, relevant to the user. The most common methods of achieving this are either via an input device, such as 3D mouse, used to rotate the display, or by tracking the motion of the user's head and updating the graphical display accordingly, such that the correct perspective information is sent to each eye.

Boritz and Booth [4] evaluated a reaching task for targets with and without stereo viewing and with and without head tracking. Stereoscopic feedback did significantly improve performance, but no effect of head tracking was found. However, the default head position was close to the correct center of perspective, therefore there may have been little difference in the head tracked and non-head tracked cues. Results of Ware and Franck [15] suggest, however, that relative object motion was more beneficial than stereo cues in reducing errors during exploration of abstract visualisations of data. The method for producing the relative motion (head motion or object rotation) did not significantly affect performance.

4. Virtual Sketching

As part of on going research on the Tacitus project [12], we are investigating the role of haptic force feedback interfaces in allowing applied artists to transfer their ideas to a digital medium with little or no loss of fluency of externalisation. During the early phases of design, a designer will wish to explore possible creative solutions via externalisation of ideas in a fast and intuitive manner. If this fluency is to be achieved in a 3D virtual environment, it is necessary to address the issues of comprehension, target acquisition and trajectory following in 3D space. The main motivation behind the following investigation is to objectively assess the impact of a specific haptic aid in this task. We have adopted virtual magnets (or gravity wells) due to their relative success in 2.5D environments. In our current virtual sketching prototype, gravity wells are positioned at the start and end point of lines sketched by the user. This allows these points to be rapidly located, in order to join lines together with a view to constructing surfaces.

5. Experimental Procedure

The equipment used in the trial was a Reachin Developer Display with a PHANToM haptic force feedback device, equipped with the instrumented stylus.

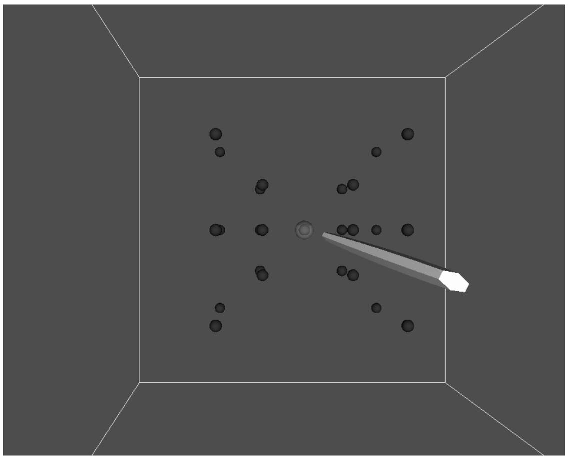

Figure 1. Virtual environment used in trial. The outer 12 spheres are targets, the inner 12 are distractors. The reset position is indicated by the sphere in the centre.

The virtual workspace employed in the test is illustrated in Figure 1. The workspace consists of a number of "nodes" that are represented in 3D space by red spheres of diameter 3 mm. A node is positioned at the centre of the workspace, representing the reset position for each iteration of the trial. At a distance of 80mm from the origin are the outer set of 12 nodes, these are the "targets" for the experiment. The inner set of 12 nodes, located at 40 mm from the origin, along a vector corresponding to each of the target nodes are "distractors". These are necessary in order to validate the study. Without distractors, an attractive force around a target will certainly improve performance, as it effectively increases the target size. This is, however, based on the assumption that the computer knows the intended target. In which case there is no need for the user to perform a pointing operation. [19] The distractors therefore possess virtual magnets in common with the target nodes.

During each iteration of the trial, the subject adhered to the following procedure. Firstly, the subject was required to return the haptic device to the origin of the workspace. This was achieved accurately by providing force feedback in the form of a spring stiffness force in order to guide the user to the origin. The user instantiated the next step of the trial by clicking the button on the haptic interface stylus. Upon clicking and holding the button, a randomly determined target node was visually indicated using a semi-transparent green sphere of radius 5 mm. It was the subject's task to move as quickly and accurately as possible to the target. When sufficiently close, the subject released the stylus button. No emphasis was given in the instructions provided to the subject regarding speed or accuracy of movement. The position of the haptic device was recorded when the stylus button is released, along with the position of the target, and the time elapsed since the subject pressed the stylus button.

The conditions for the investigation were as follows:

1. ***2D visual feedback with no haptic feedback.*** The subject viewed the virtual environment (V.E.) using the co-located Reachin display, but in mono vision. The stereo vision glasses were still worn, however, to eliminate the effect of the tinted lenses on performance.

2. ***3D visual feedback with no haptic feedback.*** As for condition 1, but the stereo emitter is enabled, thus providing stereoscopic visual feedback to the subject.

3. ***2D visual feedback with haptic feedback.*** The visual cues provided are identical to the set up described in condition 1. Haptic feedback is provided using "virtual magnets", which provide a linear spring force towards a point in 3D space, corresponding to the location of the target. The magnet is enabled at a distance of 10mm from the target, with a stiffness of 500 N/m. The qualitative effect of the small magnet is similar to falling in to a small groove or depression in 3D space.

4. ***3D visual feedback with haptic feedback.*** The visual feedback condition is identical to that described in condition 2. Haptic feedback is provided in the form of the virtual magnets outlined in condition 3.

Each trial consisted of 20 iterations, as described above. Each subject completed 2 trials, under each of the four experimental conditions. The actual order of the 8 trials were randomised.

Each subject was given time to practice, first with the demo software provided with the Reachin equipment, in order to familiarise them with the hardware capabilities, then with the experimental set-up under the four different conditions. As the test was relatively simple, the subject gave verbal indication when they felt that they had sufficient practice at the task, and were ready to proceed with the investigation.

14 students from Edinburgh College of Art acted as paid subjects for the experiment. None had any experience with haptic interfaces prior to the experiment.

6. Hypothesis

The independent variables to be tested in the investigation are the provision of haptic feedback and the provision of stereo graphics cues. The dependant variables to be measured are accuracy and time to achieve the target. The experimental method is a within subjects design.

In accordance with findings in related literature, it is hypothesised that the use of haptic virtual magnets will provide a significant increase in subjects' accuracy scores. Further, it is hypothesised that the haptic feedback will not affect target acquisition times. However, it is anticipated that stereo graphic feedback will help the subjects to improve their temporal measure of performance.

7. Results

The results of the experiment are summarised in Figures 2 and 3. Figure 2 illustrates the effect of the provision of virtual magnets and stereo graphics on accuracy measures. The provision of haptic feedback was found to have a significant effect on subject's accuracy in attaining the targets ($F(1,13) = 10.04$, $P < 0.01$), as was the provision of stereo graphics ($F(1,13) = 8.82$, $P < 0.05$), although as clearly indicated on the graph there was a significant interaction of the two factors ($F(1,13) = 6.65$, $P < 0.05$).

It was hypothesised that haptic feedback would aid accuracy in target selection, and this is confirmed by the results. However, stereo feedback also aids performance in the experiment, and from Figure 2 it is evident that if stereo graphics are utilised, significantly less benefit is reaped from using haptic feedback. Similarly, an application for which the targeting test is ecologically valid where haptic feedback is provided would not justify the cost necessary for inclusion of stereo graphic cues.

There was, however, a highly significant effect for subjects in the experiment ($F(13, 13) = 26.43$, $P < 0.01$). Indeed, some subjects incurred a detrimental effect on accuracy when stereo graphics or haptics were

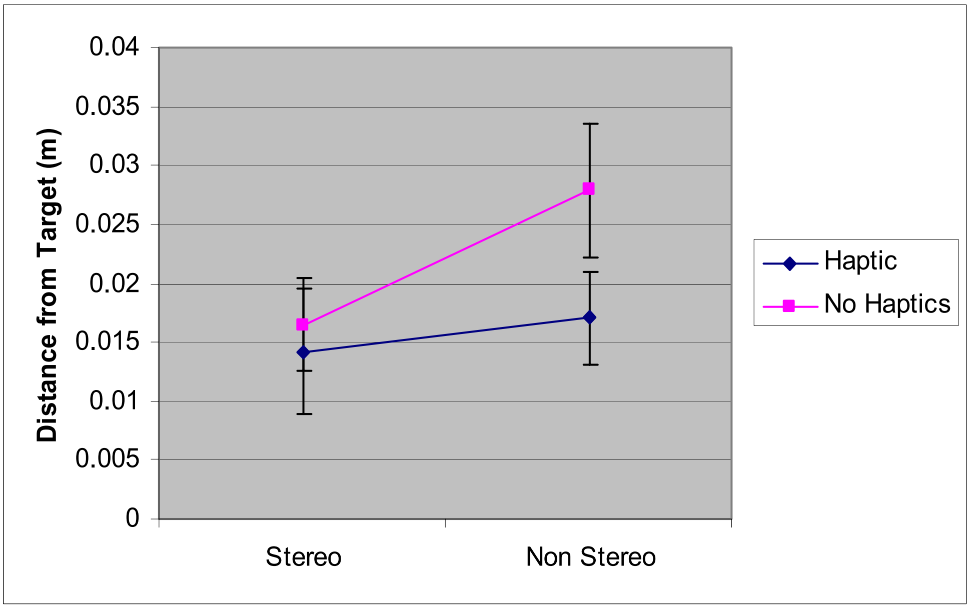

Figure 2. Effect of provision of haptic feedback and stereo graphics cues on subjects' accuracy.

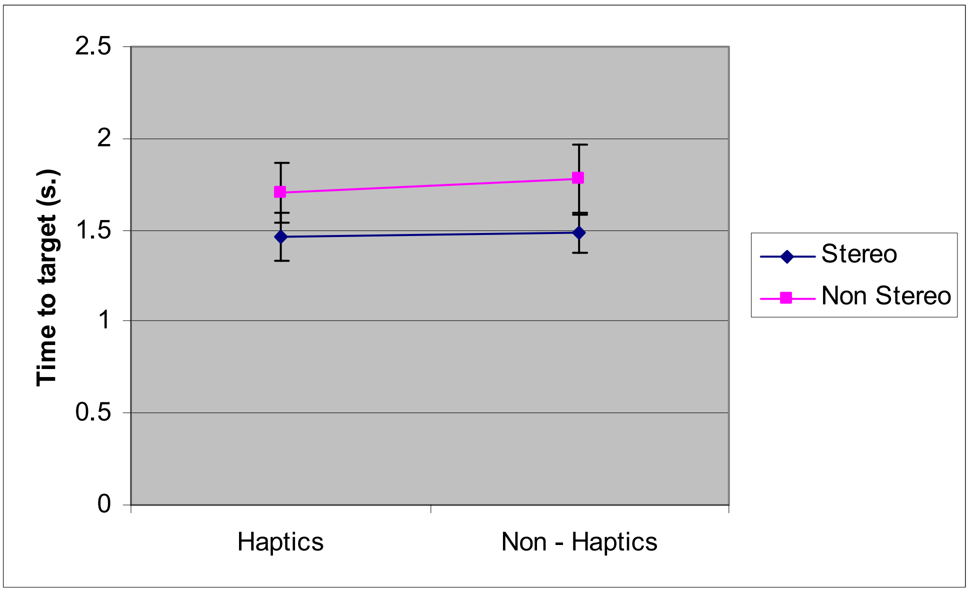

Figure 3. Effect of provision of haptic feedback and stereo graphics cues on subjects' time to attain targets.

employed. Any recommendations arising from the investigation are therefore made with caution. It is, however, likely that some short term practice (or a greater number of subjects) would eliminate this discrepancy. Short term training has been shown to improve performance in a shape recognition task [18].

Figure 2 illustrates the effect of the independent variables on targeting times. Haptic feedback does not significantly improve subjects targeting times in the test ($F(1,13) = 0.209$, $P > 0.05$). This is most likely due to the effect of the distractors hindering the subjects' movement. Conversely, as was hypothesised, the stereo graphics have a significant effect on the temporal measure of performance ($F(1,13) = 6.99$, $P < 0.05$). As with the accuracy metric, there was a significant variation amongst subjects ($F(13,13) = 51.46$). Due to this wide fluctuation, some subjects were against the general trend of results and slightly improved their performance with haptic feedback, or performed worse with stereo feedback.

8. Conclusion

The results of the investigation suggest that for simple targeting tasks, the provision of haptic force cues via virtual magnets can help users to improve their accuracy. Provision of stereo graphics feedback can also help performance, and can also help to improve the speed with which subjects can attain the targets. In this experiment, haptic feedback provided no benefit to subjects' target selection times, which, it is hypothesised, is due mainly to the presence of "distractors" in the task, which are necessary to ecologically validate the research.

Wide variability was observed across the subjects in the experiment, despite brief informal training with the device and the task to be completed. As such, caution is to be recommended when generalising the results of the experiment across differing levels of expertise with a haptic device. It is suggested that for future studies it may be beneficial to investigate the effect of training in such target acquisition trials, as subjects naturally have a variability in their aptitude to using the novel equipment.

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