Towards eye based virtual environment interaction for users with high-level motor disabilities

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ABSTRACT

An experiment is reported that extends earlier work on the enhancement of eye pointing in 2D environments, through the addition of a zoom facility, to its use in virtual 3D environments using a similar enhancement. A comparison between hand pointing and eye pointing without any enhancement shows a performance advantage for hand based pointing. However, the addition of a 'fly' or 'zoom' enhancement increases both eye and hand based performance, and reduces greatly the difference between these devices. Initial attempts at 'intelligent' fly mechanisms and further enhancements are evaluated.

1. INTRODUCTION

Virtual Environments have much to offer motor impaired users such as entertainment, rehabilitation training, collaborative activities with users in remote places and the opportunity to experience a sense of place afforded by remote locations. A key aspect in realising this is the provision of interaction devices and techniques that are efficient in utilising the residual capabilities of the motor impaired users, whilst not requiring undue effort or imposing undue workload.

Eye gaze-based pointing devices have been used for interaction with 2D graphical environments for some time and can offer access to these environments for people who may have few other choices of interaction device. However, anecdotal evidence suggests that these pointing devices are an inefficient and unsatisfying means of interaction and manipulation due to the inaccuracy of eye-tracking systems, making direct interaction with environments difficult for disabled users who use these devices. Our previous work has suggested that much of this inefficiency and low user satisfaction with eye-based interaction can be greatly resolved by the use of supporting 'soft' devices to aid interaction (Bates 2000, Bates and Istance 2002).

The challenge now lies in utilising the knowledge and experience gained from 2D environments in enabling effective eye-based interaction with 3D virtual environments. An essential element in doing this lies in the provision of, and evolution to 3D, of the 2D 'soft' device enhancements shown to enable effective eye-based interaction in 2D environments.

2. PREVIOUS WORK

2.1 Eye-Gaze Interaction in 2D and 3D Environments

One of the goals of 3D virtual environments has been to enable users to apply the natural skills that they use in the real-world to their interaction with the virtual world. One of the advantages claimed for interaction techniques based on eye-gaze for 2D interaction is that these are more natural than the usual hand-based techniques, which involve a mouse or a joystick (MacKenzie et al. 2001, Jacob 1995, Jacob 1991). Also eye-based interaction in 2D contexts has been expected to be more efficient and faster as a means of pointing than other devices (Edwards 1998, Jacob 1995, Salvucci and Anderson 2000, MacKenzie 1992). Eye gaze is more direct as a user will first look at a target and then manoeuvre a pointer to it by means of a series of coordinated hand movements. Eye gaze should therefore be highly suited to interacting with 3D virtual

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environments with its promise of enhanced naturalness and efficiency, if the limitations of eye-based interaction found in the context of 2D interaction can be overcome.

An experiment where hand-based pointing, using a joystick, and eye-based pointing were compared for targets of different sizes within a virtual environment has been conducted (Asai et al 2000). Here they reported that eye-based pointing was 10 times faster on average across all target sizes than hand-based pointing. They note though that lack of familiarity with the joystick may have been responsible for some of the longer times recorded in the hand-based condition.

A significant example of the early use of eye-gaze in interacting with 3D virtual worlds was the 'self-disclosing' display (Starker and Bolt 1990). Eye-gaze was used to assign an 'index of interest' to objects in a virtual world presented on a desktop display. The system responded dynamically to changes to the assigned indices of interest by adapting a spoken commentary about the world to reflect either a particular interest in one object, or an interest spread across a group of objects.

This technique was subsequently used as a gaze-based interaction technique within a virtual environment (Tanriverdi and Jacob 2000). This entailed that objects in a virtual environment receiving a sufficiently high index of interest increased in size and revealed their internal structure. This is not a 'zoom-in' of the observer towards the object of interest, but rather a 'zoom-out' of the object towards the observer. Tanriverdi and Jacob compared the performance of this technique with that of a hand-based pointing technique for a task which involved selecting objects in an environment to discover which contained various target stimuli. These targets could either be reached in the hand pointing condition while the user was stationary, or by the user moving 5 to 15 inches forward. A performance advantage in favour of gaze-based pointing over hand-based pointing was found, but only for targets which required the subject to move forward. The gaze pointing condition enabled selection of the same targets without the user having to move. This presumably afforded some advantage to the gaze condition regardless of any inherent difference between eye and hand as a pointing modality.

A similar experiment was conducted (Cournia et al 2003) but used the 'ray-casting' interaction technique for both hand and eye conditions. There was no 'zoom-out' for any target, only a fade to reveal inner structure. They found a significant difference in favour of *hand-based* pointing for targets at distances where Tanriverdi and Jacob had found advantages for eye-based pointing. These two pieces of work suggest that the benefits of eye-based pointing in virtual environments are contingent on the apparent size of target (assuming targets located further away are smaller) and on the interaction technique used.

2.2 Enhancing Eye-based Pointing in 2D and 3D Environments

Interaction in 3D environments can broadly be characterised as object manipulation, navigation and application control (Hand 1997). Zooming or flying in towards an object can be seen both as a navigation technique and as an object manipulation technique. Temporarily zooming-in on an object of interest to select it makes it easier to select objects with an inaccurate pointing device (Bates and Istance 2002), although it is important to be able to zoom back out to the original position to prevent loss of context and orientation. Without the return to the original position from where the zoom action was initiated, zoom becomes a fly navigation technique ('fly where I point' or 'fly where I look').

'Intelligent flying' can utilise a similar technique to the 'index of interest' where initiating a 'fly' action assumes the target to be that object with the highest index of interest. Additionally the fly can stop at a reasonable distance in front of the assumed object of interest so that it does not fill too much of the visual field, or indeed, to ensure that the user does not fly straight through the object. Moving the gaze point during the fly can either effect small corrections to the flight path or indicate the intended object to fly to is not that which has been assumed by the system.

3. DETERMINING THE BENEFITS OF FLYING TO 2D OBJECTS

3.1 An Experiment in 2D

An experiment was conducted in a complex 2D GUI test environment to measure the effect of providing a basic 'fly', or zoom, enhancement (Bates and Istance 2002). Hand and eye based pointing devices, or hand and eye mice, with and without the fly enhancement were used to manipulate GUI objects of four angular sizes based of the angle the objects subtended from the eye of the user. These ranged from 0.3^0 to 1.2^0. Interaction typically lasted for 20 minutes and incorporated 150 test tasks for each of the 6 users in the experiment. The objective efficiency (based on time and quality of interaction metrics) and subjective user satisfaction (based on ratings of workload, comfort and ease of use) of the manipulation were measured. These objective metrics were derived from the ISO9241 part 11 standard and the ESPIRIT MUSiC metrics method and previously validated. The subjective metrics were obtained from a set of rating scales, similar to the NASA TLX. For this experiment the basic fly enhancement was under the full control of each user via micro switches rather than under intelligent software control in order to determine at what distance of fly into the environment the users opted to stop the fly and start manipulation.

3.2 2D Flying Experimental Results

Fig. 1 shows the task efficiency metrics for the hand mouse, the eye mouse without fly and the eye mouse with the fly enhancement for each of the target size categories. The results for the eye mouse without the fly-enhancement (Fig. 1, 'Normal' mode) showed near-unusable efficiencies for the smallest object at 18% task efficiency. Efficiency increased, as expected, with increasing target size. It was notable that even with the largest object size that the eye mouse efficiency was less than the hand mouse efficiency at the smallest target size.

Examination of the results of the eye mouse enhanced with the 'fly' soft device (Fig. 1, 'Fly' mode) showed dramatic increases in efficiency for all object sizes, with the non-fly performance on the largest target being equalled by the 'fly' efficiency on even the smallest target size. Note that this improvement includes the detrimental overhead of manipulating the 'flying' during interaction; with the measurement of efficiency including penalties for time spent controlling the fly and errors in controlling the fly distance.

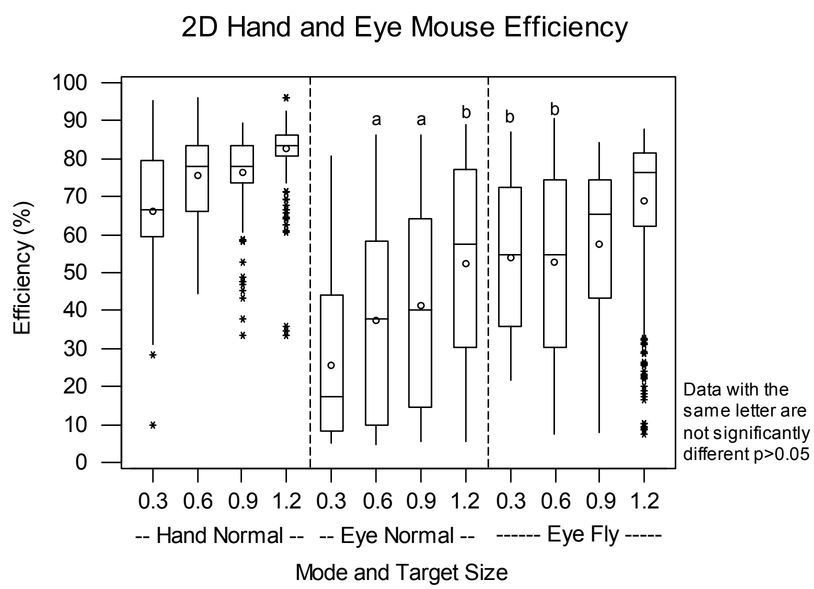

Figure 1. *Hand and eye mouse efficiency and the effect of object size and flight in 2D.*

Examination of the efficiency results by object size showed a clear relationship between object subtended angle and use of fly, with fly being increasingly used as object angles decreased (Table 1). For eye-based pointing the effective object size after flying was near constant at 1.7 degrees for all objects. These results gave the basis for calculating a 'smart fly' automatic stopping distance in front of an object for the device.

Table 1. *Eye mouse effective flown object subtended angles at 2D fly stop point.*

Original angle subtended	Enhanced eye 'flown' angle
0.3°	1.6°
0.6°	1.6°
0.9°	1.8°
1.2°	1.7°

Examination of the satisfaction ratings (Fig. 2) showed high levels of workload for the eye mouse, although with a slight decrease in rating for the enhanced mode. This was encouraging as the decrease was in spite of the overhead of additional workload controlling the fly. As expected, comfort levels remained unchanged as there was little that would affect comfort during use. There was a slight increase in device ease of use for the fly condition. It is likely that greater efficiencies and larger decreases in workload and increases in comfort and ease of use will arise from an automated 'smart fly' facility where the user does not need to actively control the fly.

Figure 2. *Hand and eye mouse satisfaction and the effect of flight in 2D.*

In conclusion, the provision of a zoom or fly enhancement greatly increases the efficiency of eye-based pointing on a 2D GUI, without adversely affecting subjective ratings of comfort or workload. Furthermore, when the user has full control over the extent of the zoom, it is used such that targets of originally different sizes all subtend approximately 1.7^0.

4. DETERMINING THE BENEFITS OF FLYING TO 3D OBJECTS

4.1 An Experiment in 3D

An experiment was conducted in a virtual environment to examine the extent to which hand-based and eye-based pointing would benefit from a similar fly enhancement to that previously examined with the 2D zoom enhancement. The hand-based and the two eye-based conditions (one with fly enhancement and one without) all used ray casting as the interaction technique, as did Cournia et al. previously.

Unlike previously reported work, which has used an immersive head mounted display, this experiment was conducted in a reality centre located at De Montfort University, equipped with passive stereoscopic images across an 8-metre wide 150^0 cylindrical screen. In all conditions, users were seated 6 metres away from the curved screen. A desk mounted SMI RED eye tracker was used for eye-based pointing, and a desktop mouse was used for the hand based pointing in order to enable direct comparison with the 2D environment. Six users took part in the experiment and a within-subjects design was used.

4.2 Experimental Task

The task was to select one of a group of virtual students in a virtual lecture theatre. The required target to select was indicated by a hat appearing on the student. Students at the back of the lecture theatre subtended the smallest visual angle in the experiment. The students on the four rows subtended the same four visual angle sizes as in the first 2D experiment.

An illustration of the experiment in the VE is shown (Fig. 3). Here the upper left frame shows the VE before a fly is invoked. The end of a vector from the user's eye through the VE can be seen as a grey cube in the middle of the picture, with the desired target object signified as the person wearing a hat. The upper right frame shows the subject 'flying' rapidly (12.5m/s) toward the target object. Finally, the lower frame shows the target object being selected with the hat flying off and away from the target. Interaction in the experiment typically lasted for 20 minutes and incorporated 144 test tasks for each user. As before, the objective efficiency and subjective user satisfaction of the manipulation were measured.

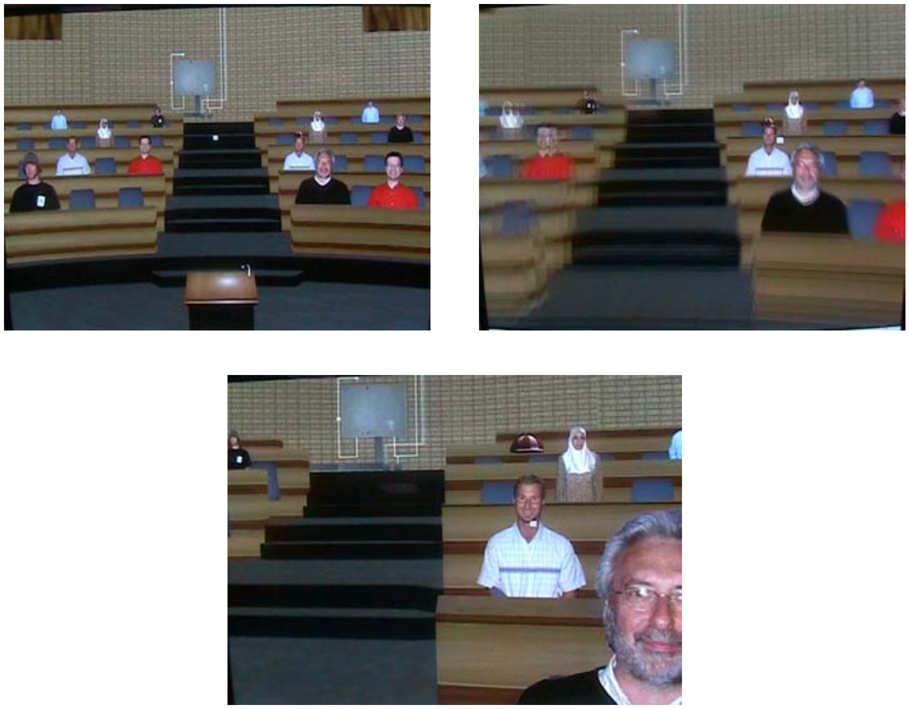

Figure 3. *Flight and object selection in the VE.*

4.3 D Flying Experimental Results

Following the procedure of the 2D experiment, the results were broken down by target size visual angle for all devices. For the hand device, objective task efficiency and subjective user satisfaction (Figs. 4 and 5, left hand and centre sets of data only) showed that device performance was highly dependent on target size, with poor performance for the smaller object sizes. Comparing the hand mouse efficiency in a 2D environment (Fig. 1) to that in the 3D environment (Fig. 4) showed a marked drop in performance for all object sizes in the 3D environment. Enhancing the hand mouse with the ‘fly’ soft device (Fig. 4, ‘Fly’ mode) showed large and significant increases in efficiency for the smallest three object sizes, with no significant improvements for the largest object size, where fly was rarely used.

The subjective workload ratings (left bars in each graph sub-section Fig. 5) showed increased workload and lower ease of use in the 3D environment compared to the 2D environment (left bars in each graph sub-section Fig. 2). It was notable that observed workload ratings were lower, and the ease of use ratings were higher in the 3D environment (centre bars in each graph sub-section Fig. 5) when the fly enhancement was used with hand-based pointing.

The efficiency results for the eye mouse without the fly-enhancement (Fig. 6, ‘Normal’ mode) showed extremely low efficiencies for the smallest objects, with efficiency increasing, as expected from the 2D results, with increasing target size. As with the 2D results, the eye mouse showed lower performance than the hand mouse, although the differences were considerably reduced between the devices in the 3D environment. There is no difference for the smallest target size, but as target size increases hand pointing outperforms eye pointing. This difference is similar to that found by Cournia et al quoted earlier. With the fly enhancement (Fig. 6, ‘Fly’ mode) the efficiency for all target sizes was increased, with object size now having a lesser effect on efficiency, and the eye mouse achieving near parity with the hand mouse. Examination of the satisfaction ratings (Fig. 7) showed improvement for all ratings for the enhanced mode. As with the hand mouse, it was notable that the fly enhancement reduced the observed workload ratings and increased the observed ease of use ratings in the 3D environment.

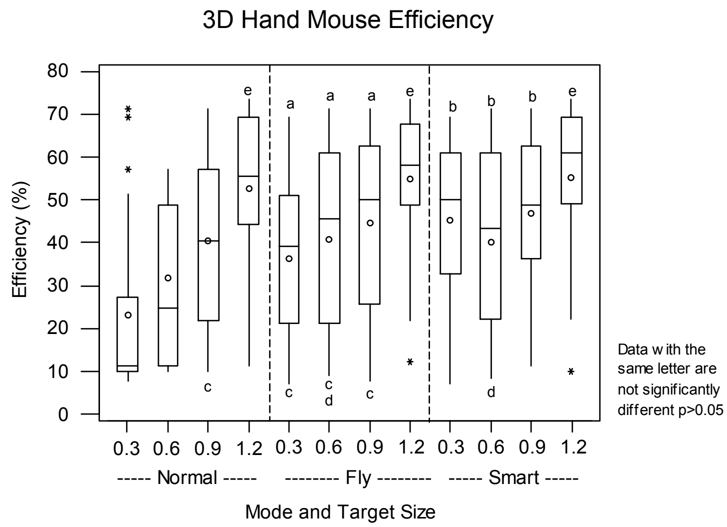

Figure 4. *Hand mouse efficiency and the effect of object size and enhancement in 3D.*

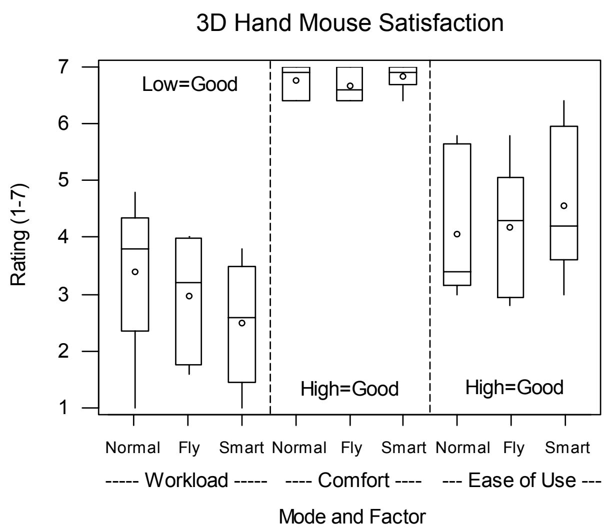

Figure 5. *Hand mouse satisfaction and the effect of enhancement in 3D.*

As before, the efficiency results gave the basis for calculating the stopping distance in front of an object for both of the devices (Table 2). Unlike the 2D condition, there was less consistency in the level of target magnification at the point when the target was selected.

Table 2. *Eye mouse effective flown object subtended angles at 3D fly stop point.*

'Normal' angle subtended	'Fly' hand effective angle	'Fly' eye effective angle	'Smart' hand effective angle	'Smart' eye effective angle
0.3°	1.3°	2.2°	1.3°	2.1°
0.6°	1.4°	2.6°	1.4°	2.2°
0.9°	1.5°	3.3°	1.5°	2.2°
1.2°	1.9°	3.0°	1.6°	1.9°

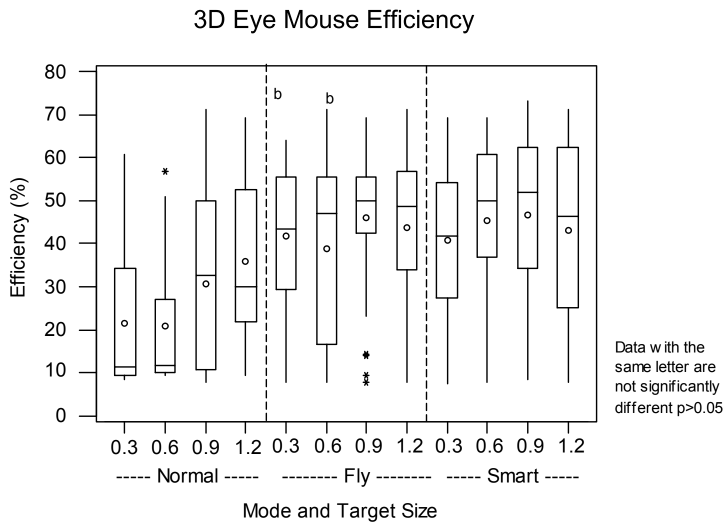

Figure 6. *Eye mouse efficiency and the effect of object size and enhancement in 3D.*

Figure 7. *Eye mouse satisfaction and the effect of enhancement in 3D.*

5. DETERMINING THE BENEFITS OF INTELLIGENT FLYING

5.1 An Experiment with 'Intelligent' Flying

Based on 3D experimental results, a 'smart' stopping distance was set at a distance where the visual angle of an object would subtend 2.4°; a compromise to give greatest ease of manipulation without overly enlarging objects and potentially disorienting the user, but also flying sufficiently close to give ease of selection. To do this the fly enhancement was modified to monitor the point of interest in the environment, and the required fly distance toward target objects based on their apparent size, with the fly automatically being stopped when the object subtended a 2.4° visual angle. After manipulation, the user returned to the original starting point by initiating an automatic fly back. This gave the first elements of an 'intelligent' fly, with the fly automatically stopping at an optimal distance, and then returning to the pre-flight position. In the same manner as before, a trial was conducted with the intelligent fly enhancement using hand and eye pointing.

5.2 'Intelligent' Flying Experimental Results

The results for the 'intelligent fly' hand and eye mice were appended to the 'normal' and 'fly' results to aid comparison between the three modes of operation (Figs. 4 to 7). Overall, device efficiency was essentially unchanged from the basic 'fly' mode, showing that although test subjects tended to fly closer to objects with the eye mouse (Table 2) than the estimated ideal distance, there were no performance benefits from doing so. In addition, the intelligent fly suggested reduced workload is possible in comparison to the basic fly mode.

6. CONCLUSIONS

The work reported has demonstrated that the benefits of enhancing eye pointing by zoom previously demonstrated in 2D interaction are also apparent in 3D interaction. Our results comparing eye and hand pointing in virtual environments accord with those reported elsewhere, and show a performance advantage for hand based pointing. Our work shows that this benefit is only apparent for larger target sizes, however, when a zoom or 'fly' enhancement is provided the performance levels of eye based pointing increase to a similar level to that of hand based pointing. We have not been able to demonstrate the same consistency of zoom that was apparent in the 2D environment. Our initial attempts to go further and introduce a degree of 'intelligence' have indicated some success. The limited but promising results suggest that more effort is required to add further intelligence to interaction to gain performance benefits.

The addition of an intelligent control based on optimal object subtended angles is currently under investigation and is expected to further enhance performance with eye based pointing in 3D environments. In this way, the naturalness and efficiency benefits offered by this modality should be realised to a greater extent. This work forms part of, and contributes to, the efforts of the Communication by Gaze based Interaction (COGAIN) fp6 Network of Excellence.

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