Identifying Optimal Attributes in 3D Interface DevicesSite

Martin Henschke
Research School of Computer Science
Australian National University
0200 ACT Australia
martin.henschke@anu.edu.au

Tom Gedeon
Research School of Computer Science
Australian National University
0200 ACT Australia
tom.gedeon@anu.edu.au

ABSTRACT

We measured the precision and ease of use of three separate interface devices designed to be operated in 3D space, specifically with 3D environments and tasks. A gyroscopic, handheld mouse, a finger mounted gyroscopic mouse and a wired glove accompanied with a Microsoft Kinect were used to see which attributes of the devices were most important in their use. Results found interfaces with the closest analogue to typical computer usage performed the best, with participants commenting mainly on the importance of precision and accuracy over the 'naturalness' or appropriateness of the style of interface. We conclude that usability factors and maximizing user effectiveness in an environment far outweigh UX concerns of immersion or closeness to interface paradigm.

Categories and Subject Descriptors

H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *graphical user interfaces(GUI).*

General Terms

Experimentation, Human Factors

Keywords

3D Visualizations, Virtual Environments, 3D Input Devices.

1. INTRODUCTION

The 3D environments and data visualizations have become a common element of modern computer usage. From their basic and most common setting in video games, to virtual interactive spaces such as second life, and even in more contemporary settings such as search engines and map displays, the need for users to be able to interact with data in 3D is now commonplace. This has allowed a more intimate way of being able to view and manipulate data, as well as providing a more engaging interface for the user. With this, however, has come an increased interest in finding novel and better interface methods to interact with this data; as typical inputs are constrained to 2 dimensions, additional input is required to perform navigation and movement in the additional dimension presented. Interfaces which better relate to the environments the user is interacting with are of chief interest among these.

A large area of research arising from this are ubiquitous, gestural interfaces; users operate no device but use a series of sensors to capture information about their movement, interpreted as interaction with the system. However, setup and use of equipment necessary for these sorts of interfaces is still quite high for the typical end user; though exceptions exist, device manipulation remains the typical method of interacting, even in 3D spaces.

There exists a class of devices that can be used in a standard 2D setting, but are operated by the user in a 3 dimensional space. These devices also use a suite of sensors to capture human movement but with the device in-hand, users are easier able to make precise interactions such as button presses for interacting with and manipulating data, as well as avoiding the ambiguity that comes from classifying and working with gestures, while still retaining the richness of 3D interactivity.

In this paper we will be exploring the aptitude these devices have for operating in 3D environments, and what elements make them suitable for this sort of operation. Several devices have been selected with various elements that we hypothesize are important in working in 3D environments for analysis and comparison with a user base to determine the most important considerations in selecting appropriate devices for interfaces, or in designing such devices material.

2. BACKGROUND

Several examples exist in the literature of interfaces that make use of 3D pointing or similar devices in interacting with large displays. The MIT Media Room[1] combined a motion sensor attached to the finger with spoken voice commands for absolute pointing on a large display. Angus and Sowizral[2] discusses methods for translating 2D interface devices to operate in a 3D virtual environment. A study comparing Wii remote and Kinect interfaces found a hands free interface performed tasks faster and was preferred by users to the Wii interface, which used in-built accelerometers rather than arm movements for tracking[3]

Hands-free interfaces or those with small or ubiquitous controllers are frequently used in virtual environments. Bowman and Hodges[4] considered a series of arm techniques used for object manipulation in 3D spaces, finding no clear preference between users. Another study by Cabral et al.[5] suggested users found value in the immersiveness of interface techniques in virtual spaces, although traditional mouse input tended to have higher performance.

3. EXPERIMENT DESIGN

The research question of this paper is, when using a device to perform pointing an object manipulation in a 3D environment, what factors of the device impact its optimality? We define a device as any non-ubiquitous object manipulated by the user to interact with the system, and its optimality by the factor of how well it performs, how consistent it is found to perform and to what extent it is favoured or preferred by users. We set out to explore this problem with an experiment, measuring optimality of a series of interfaces in an attempt to isolate these important factors.

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3.1 System

The environment the experiment has been conducted in is presented to the user as a bounded 3D space. Within this space, a series of objects are presented to the user which they are able to interact with, given a set of rules explained at the top of the screen and by the experimenter. These include the ability to select specific objects on the screen, and to pick up and drop them, locking them to the on-screen cursor until the user lets them go. The graphical style of the interface is that of a castle, with large rooms connected by corridors. The environment is not navigable by the user; instead the system determines where the user is to be taken depending on what stage in the trial they have achieved. The environment was displayed on a wall-mounted flat screen television, with users standing 1-2 meters away from it.

A cursor was displayed to indicate where the user's pointer was positioned as a rotating star. The star would release a burst of smaller stars when a selection action was performed by the user, and would change color from green to red when the user was attempting to perform a drag. Objects on screen would also change colour or otherwise make it clear if they were being selected and dragged successfully.

There were a total of three variations on the tasks that users were asked to perform:

- Selection tasks, in which the user was asked to select a series of ghosts that appeared in random positions and sizes on the screen. Selecting each target would cause it to disappear and a new one to appear. Ten ghosts needed to be selected to progress.
- Grabbing tasks, in which the user had to select a key appearing at the bottom of the screen and drag it over a target area (a locked door). The key had a consistent size, so this exercise judged moving the object around in 3D space.
- Dropping tasks required the user to select a series of randomly positioned and sized fireflies in a room, grab them and drop them inside a small cage at the centre of the screen.

The selection interaction was required for each experiment and was used as a base measure of performance in the trials. The drags and drops, being more difficult tasks to perform were measured separately.

3.2 Input Devices

Three separate input devices were tested in this experiment: Figure 1 shows each of the three devices, as well as the hand dynamometer used in analysing arm strength and fatigue.

3.2.1 Gyroscopic Air Mouse

The Omni Motion Air Mouse can operate as both an optical and gyroscopic pointing device. It is roughly the same size and button layout as a standard desktop mouse. An internal gyroscope is capable of detecting sensitive rotation of the device, and this was used exclusively by participants in moving the cursor on the screen with this device. The device was held in the palm of the user's hand, with the thumb being used to access buttons. The left and right mouse buttons were used for selections and grabs respectively.

In our experiment, the gyroscopic mouse is the closest analogue to a traditional mouse used in typical computer usage, and was the one expected to be most familiar to users.

3.2.2 Wired Glove and Camera

A combination of an Essential Reality P5 Wired Glove and the Microsoft Kinect were used to produce a direct pointing interface in the simulation. The Kinect sensor captured the skeleton position of the user, and used the vector between the elbow and wrist to project a line that determined the direction the user was pointing. By calibrating the users pointing to a monitor surface, the user was able to point their arm from any orientation and any position to move their cursor on the screen.

The actual selection and grab interactions were captured by the P5 wired glove, worn on the right hand. A series of bend sensors along the fingers were used to capture the flexion of each digit. In our experiment, flexing the index finger was used to indicate a selection, while forming a fist and flexing all digits performed a grab. As the glove is strictly handed, only right handed or ambidextrous users were able to participate.

This interface provided the greatest degree of user-system interaction, as pointing was direct and user-defined, so besides explaining its operation, almost no training was necessary to learn to use it.

3.2.3 Finger Mouse

The Neo Reflections Wireless 3D Finger Mouse operates with the same technology as the gyroscopic mouse, i.e. an internal gyroscope that measures rotation to move the cursor. However, the device is substantially smaller in size and is mounted by a small plastic mount to the index finger of the user. Only small movements of the index finger are necessary to move the cursor rather than full hand movements. The device is also substantially lighter, and remains dormant unless the user touches their thumb to the outside of the casing.

Being the lightest and most sensitive of the devices, we anticipated this would have very high performance. Of interest to the outcome of this experiment is that both this device and the Gyroscopic Air Mouse can also operate as typical optical mice.

Figure 1. The devices used in the experiment.

3.3 Experimental Methodology

Please Each experiment conducted had a participant use two of the three devices in sequence. Each trial involved ten selection tasks, ten grabbing tasks and ten grabbing and dropping tasks. After completing each task in a trial for a single device, the participant was permitted a 5 minute break before performing the second.

At the end of each experiment, users were asked to fill out a short questionnaire providing their preference for each device on a Likert scale and in a series of qualitative comments. In addition to this, on the suggestion of an occupational therapist, a grip dynamometer test was employed at the end of each trial to measure changes in arm strength over the course of the experiment (in the event fatigue physically weakened participants).

In addition to this, the program recorded all actions the user took in operating the system. As targets and objects displayed in the visualization were in 3D, target size and distance from cursor were calculated in post-processing of data. This information informed us of how quickly users made selections and grabs, how long each task took and how many errors or mistakes were made in the process.

4. RESULTS

A total of 18 participants were used in this experiment. Each couplet of trials had a total of 6 participants, so each device was used and reported on 12 times.

4.1 Performance

Table 1. Mean Times and Standard Deviation for each Device in Performing Selection Trials

Device	Mean Time (μ)	Standard Deviation (σ)
Air Mouse	2.68s	1.54
Finger Mouse	2.84s	1.18
Glove	3.30s	1.75

Each device was analyzed according to a Fitts's Law projection, but none produced a sufficient correlation consistently for their values to be meaningful in this experiment. This was expected to be for two reasons: firstly, the difficulty of tasks never had a great variance in difficulty, or $\left(\log_2\left(1+\frac{D}{W}\right)\right)$ as measured by the law, as very small targets were considered unfeasible for selection in the interface. Secondly, a degree of smoothing was applied to the ballistics of cursor movement; this was added as a necessity to the Glove interface due to imprecisions in the Kinect and carried over to other devices to ensure consistency. The addition of this smoothing we believe encouraged uses to focus on precision, despite being informed the trial was timed; this shows as error rates are very low for all devices but a much higher variance in time taken. Analysis of devices using Fitts's Law, therefore, was unhelpful.

Instead, we compared the overall time taken for each device in the trials to determine which tended to perform the fastest. We also used the standard deviation to determine how consistent each device was to use, and whether or not there was a great deal of variation in its movement. Tables 1 and 2 show the results of this analysis.

For the first set of trials, performing basic selections of objects, the fastest device was found to be the Air Mouse, with the Glove having the worst performance. However, while the Finger Mouse was notably slower, it had substantially less variation in user performance, suggesting it could be used more consistently in these trials.

Table 2. Mean Times and Standard Deviation for Each Device in Performing Grab and Drop Trials

Device	Mean Time (μ)	Standard Deviation (σ)
Air Mouse	2.85s	1.88
Finger Mouse	4.03s	3.29
Glove	4.81s	4.21

The second set of trials was less ambiguous, with the Air Mouse having both superior speed and consistency in its results when compared to the other devices. The trials also show the glove to be the worst performing interface. This could partly be the fault of the bend sensors on the glove, which were at times unresponsive (particularly if participants had small hands), and also an issue with the Kinect which occasionally suffered from a lack of precision that at times made tasks (especially the grab and drop tasks) very difficult for users. Several instances also existed in trials of users having to stop and rest their arms or reposition themselves in an attempt to reset the sensor.

4.2 Preference and Fatigue

In the questionnaire, users were asked to rank their preference of the two interfaces they were given, and list reasons why, as well as comment on any fatigue they may have experienced and issues they had using any of the interfaces.

Of the three input methods, the Air Mouse was the most popular; 8/18 participants stated it was their preferred device. 6/18 participants indicated they preferred the finger mouse, while 2/18 stated the glove was their preferred interface. In giving feedback on issues or reasons for their preference, we were able to identify 5 general areas participants discussed in their feedback: Imprecision with the interface, too sensitive, slow or unresponsive, fatiguing to use and unnatural feeling. Figure 2 shows how many times each device was mentioned in user comments with these issues.

The most commonly reported problems were to do with precision and sensitivity of the interfaces, having difficulty in selecting objects with ease or speed. Other reports included problems with the equipment failing to recognize movements; this was an issue solely of the glove that had set thresholds for accepting bends that users had difficulty in determining. Fatigue was reported by some users but only mentioned as a usability issue in the instance of the glove. Interfaces were also referred to as 'unnatural' or 'strange feeling' at times, and this seemed to be a subjective measure.

Table 3. Mean change of average dynamometer recordings from baseline to after trial with device

Device	Change in Reading
Air Mouse	1.34
Finger Mouse	2.10
Glove	0.07

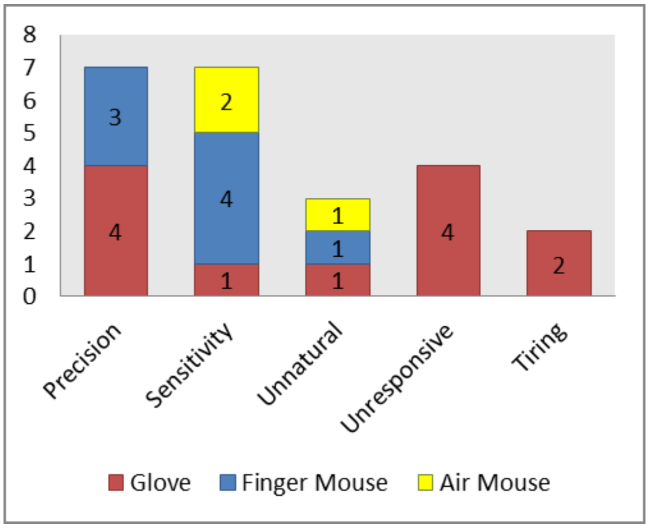

Figure 2. Mean Times and Standard Deviation for each Device in Performing Selection Trials.

Dynamometer data was taken from participants but results were not consistent enough to be reportable. Participants would both increase and decrease from their baseline after trials, by varying amounts. As a result, we found the dynamometer was not a useful measure of fatigue or effectiveness after using these devices. The change in readings from baseline dynamometer results after every trial are listed in Table 3.

Users did however report fatigue for each device on a scale in the questionnaires. The mean fatigue participants experienced with each device is listed in Table 4.

Table 4. Reported fatigue from each interface on a scale from 1 to 7

Device	Mean Fatigue
Air Mouse	2.66
Finger Mouse	4.00
Glove	5.92

5. DISCUSSION

In observing the performance of each device it is clear the gyroscopic mice greatly outperformed the camera-based interface. While some of this may be due to imprecision in the bend sensors on the glove, it is more greatly attributed to the far higher level of precision the mouse was able to produce over the Kinect. Issues with skeletal tracking with the Kinect camera would often lead to the pointing location changing erratically during trials, as the elbow and shoulder are frequently eclipsed from view when participants operate the interface. Measures such as changing posture and position came some way to fixing this but the interface was never as smooth and precise as the gyroscopes.

It was surprising to see a substantially higher performance with the air mouse over the finger mouse, given both operate with effectively the same internal technology. Part of this success may be attributed to the device being larger and thus easier for participants to handle, or the analogue between it and using a standard desktop mouse (which many commented as being one of its strengths in the questionnaires). Differences in simple selection are relatively small, but in performing the more delicate task of moving objects around the screen, the mouse was found more precise by participants.

The differences between the results between the Air and Finger mice is interesting, since we expected better results with the Finger mouse, as the weight of the device is reduced, and so user pointing would be more similar to natural pointing with our hands. This contrary result is consistent with results in a paper on wands and other holdable devices [6]. It seems likely that holding a device is beneficial. In our future work we can investigate device size and weight and time trade-offs, as surely there are a maximum sizes/weights that meaningfully affect the way users point, and length of experiment, which could objectively demonstrate fatigue effects of different devices.

The results of the questionnaire were similarly revealing to the priority of the user when considering the design principles of the experiment. The majority of criticisms levelled at the system were to do with difficulty in performing small or precise movements with the system; where these interfaces acknowledge and work with the fact they suffer from poorer precision in these environments but provide a greater level of immersion and connection to the interface as a tradeoff. With only 3 comments regarding this (and no positive comments), this suggests that users prioritize performance, particularly precision over the user experience.

6. ACKNOWLEDGEMENTS

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