Evaluation of a Handheld Touch Device as an Alternative to Standard Ray-based Selection in a Geosciences Visualization Environment

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ABSTRACT

We investigate the use of a consumer hand-held touch interface (iPod Touch) for selection of objects in a 3D visualization environment for geosciences data (well logs). Our technique was designed to overcome selection problems arising from occlusions, distant or small targets, and by a potential for integration with low-cost trackers and smaller displays that exacerbate these selection problems in ray-based selection. The touch device presents an iconic map overview and allows selection with a touch-refine-release interaction. It is best suited to environments that lend themselves to such map representations (terrains, city layouts, building floors, etc.). Our experimental evaluation shows the touch selection is promising in comparison to standard ray pointing, reducing selection time and errors for most of the tested targets. Analysis of user motion suggests that the technique is also suitable for low-cost environments with reduced tracking accuracy: although we allowed it to be used together with pointing with a high-cost tracker, users appear not to use the pointing aspect during selection. Thus, the low-cost touch interface is useful both for enhancing high-end 3D visualization and for low-cost environments with coarser (or even no) tracking. Finally, based on our observations and previous informal work, the touch aspect of the interface seems to be more important than the display aspect, given that visual feedback in the main display is sufficient to aid selection.

Keywords: 3D Interaction, Selection, Smartphone, Scientific Visualization.

Index Terms: I.3.6 [Computer Graphics]: Methodology and Techniques—Interaction techniques; H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities

1 INTRODUCTION

Scientific datasets with many objects, when visualized, create a dense and cluttered virtual environment. 3D interaction with these datasets remains a challenging problem.

Object selection is considered a primary technique that most interactive applications should support [1]. Virtual Reality [VR] research introduced various object selection techniques. Common techniques involve hand extension techniques, handheld input devices mapped to a virtual cursor, and ray casting techniques that cast a virtual ray into the scene for selection. The ray approach is dominant, but in dense or large virtual environments, object occlusions and precision pointing for small objects are major problems for standard ray interfaces [2].

Standard ray selection uses a virtual ray extending from an input device/controller to select the first intersected object. To select an object in a dense virtual environment, a standard ray interface involves some navigation or increased precision pointing at partially occluded targets, thereby increasing selection time or disturbing the view context. This problem is more dominant when the user selects a distant target – very small movement of the user hand (due to hand instability or tracker jitter) becomes a large ray movement at a greater depth/distance, reducing users' pointing precision. The problem increases in consumer-level VR input devices with modest tracking precision and display sizes. For precision pointing with a standard ray technique, the input device should be precisely tracked using a state-of-art input system. These systems are expensive, limiting the deployment of VR-style environments and interfaces.

Low-cost devices like Nintendo Wiimote and Xbox controllers can be used as input devices. These devices suffer limitations. Ardito et al. compares these devices as low-cost virtual reality interaction devices [3]. A drawback to using the standard controllers is that the user has to learn and remember the mapping between the buttons on the input device and corresponding objective functionality in the application. Several researchers have proposed various interaction techniques using mobile touch devices in virtual reality, e.g., [4, 5, 6, 7].

In this paper, we present a study of the touch interface [8], an interaction technique that uses thumb movement on a low-cost touch input device (iPod touch) for seamless and quick object selection in a potentially-dense virtual environment. This touch interface is an effort to develop a common, easy to use 3D selection interface addressing the shortcomings of the standard ray casting in substantially occluded virtual environments. This touch interface aims to improve object selection by using the finer precision of the touch surface, making selection less dependent on tracker precision, hand stability, or occlusion-free targets. Touch input devices may allow users to pick substantially occluded targets more immediately and without depth-dependent precision requirements.

We present a comparison to a standard ray interface and further consider user hand motion. The implications of our observations for low-cost VR are also discussed.

2 RELATED WORK

Selection allows the user to search and specify an object for interaction. Hence, selection is considered as one of four basic interactions in any technique and is an extensively studied VR interaction element [1]. Various factors and design guidelines are defined that are application or task dependent.

2.1 Related Selection Techniques

Due to ray interaction dominance in VR, there are several ray-related techniques for object selection in dense/cluttered virtual environments. Olwal et al. presented Flexible Pointer, an interaction interface allowing users to bend the virtual ray around virtual objects to select a fully or partially occluded object [9].

Haan et al. proposed a method to improve effciency of selection gestures with minimal movement. This can be achieved by bending the virtual ray to the closest object which has the

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maximum score value generated by a scoring function as proposed in [10]. Pointing and the 6 degree-of-freedom[DOF] interactions like rotation, etc., are more natural interactions to the users. This can be achieved using virtual pointer metaphors in a virutal environment. However, object selection and performing 6 DOF manipulations needs improvement. Steinicke et al. proposed an improved virtual pointer metaphor where a bent secondary virtual ray is used for object selection [11]. Also, this selection technique requires high precision tracked/ 6 degree-of-freedom input device.

Kopper et al. presented the SQUAD technique, where the user preselects a set of targets using sphere-casting, and these targets are displayed as a quad menu for refinement/selection [12]. A target object is selected by reducing the number of objects through interative intermediate selections. This technique doesn't require precision pointing, but intermediate selections may disconnect the user from the scene.

Vanacken et al. presented the 3D metaphor of the bubble cursor, where they used a sphere instead of a circle to highlight the captured target inside the sphere [13]. This technique is helpful when the user is familiar with the scene, but it will be tough to search for a target. In contrast, we talk about a technique that can used to search seamlessly for a target and selection.

2.2 Interaction Using Mobile Devices in VR

Considering smartphones as interaction devices for a virtual environment, researchers explored their use as multi-DOF controllers, as interaction devices, and gesture recognition for mobile games. Chuah et al. list the lessons learned in using a smartphone as a VR interaction device [5]. Graf et al. talk about using the smartphone as an interaction device with 3D visualizations and presentations [14]. They examined the usability of position and motion sensors in these smartphones for 3D navigation.

Prachyabrued et al. presented HandyMap, an iPod touch interface allowing coarse pointing with ray-type pointing followed by refined selection using the touch surface [8]. Our experiment interface follows the HandyMap technique.

Debarba et al. presented the Level of Precision cursor for interaction with a large high resolution display using a smartphone [15]. They have two levels of precision pointing: a constrained area of high resolution and a larger area of low resolution input. They established that reaching smaller targets and fast interaction while using simultaneous cursors can be achieved in a comfortable manner.

Bauer at al. evaluated the use of a smartphone as an interaction device for large displays [16]. They conducted a study comparing the user experience with traditional input devices (like keyboard and mouse) to smartphone-based techniques. They identify that even first time users exhibit better performance in doing certain tasks using the smartphone interaction techniques when compared to the keyboard and mouse.

Olwal et al. studied that using a high resolution tracked mobile device improved selection with a large touch display when compared to the direct touch interaction [4]. Kim et al. presented FWIP - Finger Walking in Place (FWIP), a navigation technique in a CAVE [17]. This technique considers finger motion resembling human leg walking motion on a multi-touch device.

Katzakis et al. evaluated use of smartphone sensors for a 3D rotation task [18]. The results with this interaction were faster than the traditional mouse and tablet touch interactions. Hwang et al. described a 3D gesture based input method on a two dimensional touch device for interaction [19]. Sun et al. evaluated a thumb interface for menu selection on mobile equipment [20].

Although both Prachyabrued et al. and Debarba et al. presented techniques similar to the one in our study as an alternative to ray casting, they did not formally compare the performance to ray casting or to other standard techniques. Also, our results regarding user motions support the idea that such techniques could work well with low-cost tracking (or even without tracking).

3 TOUCH SELECTION INTERFACE

The touch surface presents a 2D top-down overview of a 3D subregion of the virtual environment. The position and orientation of the mapped sub region change with the controller pose and inputs. Objects are represented by labelled circles of one size, independent of the objects' size and shape on the overview as shown in Figure 1. A virtual ray comes out of the touch surface similar to the standard ray-casting. This ray indicates the input device pointing direction and can be used for a coarse pointing step, is desired. This interface exhibits ray-locking behavior where the overview display on the touch input is locked and the user can move their thumb for selection. During this interaction, the visuals on the touch device are fixed. We refer the reader to the original algorithm for the experiment interface [8].

During touch input, the object closest to the subject's thumb is highlighted both on the touch surface and the display screen in front of the subject. The selection technique is described as a touch-refine-release approach [8]. The selection action is initiated when the subject touches the touch iPod. The subject can move the thumb on the touch surface to change the target for selection. The subject releases the touch to select the highlighted object.

For experimental purpose, additional interactions like overview zoom, pan and azimuth/elevation are disabled. All the software was developed with OpenSceneGraph, VRJuggler and C++. We refer the reader to the original description for more details [8].

Figure 1: Close up view of the overview representation on iPod touch.

4 EXPERIMENT

We conducted a within-subjects experiment comparing the touch interface to standard ray casting. The independent variable was:

Interaction Technique (with two levels):

1) The standard ray technique: This requires a user to point at an object with a wand and press the wand's main trigger button. A virtual ray shows the pointing direction and the first intersected object is highlighted for potential selection.
2) The touch interface with iPod Touch (Handymap): This allows both ray and touch-based selection. It can be used similarly to the standard wand by quickly tapping the surface instead of pushing a trigger. However, subjects are shown the touch-refine-release method: When holding the thumb down instead of tapping, the ray and tracking freeze and the subject can refine selection with thumb motion. Selection is then triggered by thumb release. The object for potential selection is highlighted in the main view during thumb motion, and the changing highlight gives indirect visual feedback about thumb position. So, it is not required for a subject to view the representations displayed on the touch device.

The dependent variables were:
Object Selection Time (in seconds) – time taken to select the target object after it is indicated (highlighted) on the display.
Selection Errors – number of incorrect selections while selecting a target.
Controller Translation (in meters) – accumulated per-rendering-frame translation of the subject hand movement to select a target object during each experimental sub-session trial.
Controller Rotation (in radians) – accumulated per-frame rotation of the subject hand to select a target.

4.1 Hypothesis

We hypothesized that the touch selection interface technique reduces target selection time over the ray casting technique, especially for distant or occluded objects. The touch aspect of the iPod touch may help in quick object selection and interactions. We expect to see fewer mistakes with the iPod touch selection interface. Finally, we expect that the touch interface will significantly reduce the controller translation – both translation and rotation – especially for difficult targets.

4.2 Apparatus

We used a rear-projected VisBox-HD13 display: 160"w x 90"h (184" diagonal), with a wired intersense IS 900 Sim Tracker to track the wand or iPod touch and the user head. Stereo vision was provided with circularly polarized 3D glasses. The computer was a Dell precision T5500 with an Intel Xeon X5660 2.80Ghz processor, 12GB RAM, and NVIDIA Quadro 5000 graphics card.

4.3 Subjects

18 subjects participated: 14 males and 4 females, aged 21 to 32 years (mean of 26.5). All were right-handed. 15 subjects were students doing their master's in Computer Science. The others were 1 software development programmer, 1 research faculty of Computer Science and 1 assistant professor of Math. 5 had exposure to virtual reality systems and all other 13 played video games.

4.4 Experiment Environment Overview

The selection task used in the experiment required the subject to select highlighted target objects. The objects were well logs below a terrain. Well logs are pre-rendered polyline textures that are textured onto rectangular billboards. These billboards have constant width and varying length based on log (well) length. The entire billboard is highlighted when the subject aims at the target using the ray or touches the touch surface to select the target.

Figure 2 shows the experiment scene with well logs (target objects) used in the experiment. This visualization system was developed to interpret spontaneous potential and resistivity curves from coalbed methane wells. The dataset contains several hundred well logs creating cluttered views. We only displayed 60 wells - a subset of the database - during this experiment.

Figure 2: Application used in the experiment. It shows well logs (target objects) creating a dense virtual environment. The user is holding a tracked iPod touch interface.

4.5 Experiment Procedure

The experiment was done in two sessions - one session for standard ray interaction and the other for the touch interface. There was a minute break between the two sessions that could be extended by the subject. 9 subjects got the standard ray interface during the first session and 9 subjects got the touch selection interface during the first session. For each session, the subject had an instruction, a practice and an actual experiment period. The actual experiment sub-session consisted of 25 targets – 2 non-occluded targets, 7 partially occluded and 16 totally occluded targets. The targets were chosen to make sure that:

- Targets at various depths appeared for selection.
- Targets of different sizes appeared.
- Partially and totally occluded targets appeared.

All subjects selected the same set of targets, highlighted in a random order. The experiment normally lasted 35 to 40 minutes. Each session consisted of various components listed below:

4.5.1 Instruction Period

This period consisted of a 1-trial sub-session briefly describing the selection task with on-screen instructions.

4.5.2 Practice Period

A practice period consisted of 12-trials. During this period, the subject was allowed to take time to understand the system and get familiar with the selection interface. Before this sub-session, subjects were instructed with on-screen text describing the sub-session. When the touch interface was used, subjects were told they might be able to perform the task without looking at the iPod.

4.5.3 Experiment Period

The actual experiment period consisted of 25-trials. Before this sub-session, subjects were instructed with on-screen text describing the sub-session and asking subjects to select the target "quickly and as accurately".

4.5.4 Selection Task

Per trial, the subject selected two objects (well logs). The first target object was a constant "start target" to give a consistent starting point and the second was the actual target object for which performance was measured. In order to begin each trial, the subject had to return the hand/controller to a start position. This start position is approximately 3.5 ft above a marked position on the floor. This marker and the position were shown to the subject before the starting the experiment. The software kept track of the subject's hand position and the constant start position for the each trial. A sphere was drawn on the screen to provide visual feedback about subject's hand position. The hand was required to be within 6 inches (Euclidean distance) of the start position to begin each trial. Otherwise, a sphere on the screen turned red when the subject's hand was outside the allowed boundary and they were instructed by on-screen text to return to the start position.

The target was highlighted with blue color (different highlight colours were used for different purposes). There was audio feedback to assist the subject for correct/incorrect selections. When there was an incorrect selection, a buzzer sound was played. For a correct selection, a bell chime was played.

4.5.5 Selection Error Handling

An incorrect selection of the target object was considered as an error. When there was an error, the user had to try selecting the same target object again without selecting the start object. After 8 errors or incorrect selections, the target object was skipped and the next trial was started.

4.5.6 Questionnaire

After the experiment, the subjects were asked to answer a written questionnaire that asked them to state their preference and explain their choice.

The questions were:

1. Which interaction technique would you prefer and why?
2. How quickly were you able to learn the techniques? (The number of trials to learn each technique)
3. Which interaction technique is more strenuous and why?

5 RESULTS

5.1 Target Properties

We reference various well log properties in our following presentation of results. Properties of a target in a virtual environment may be related to performance. We would like to investigate these properties and study their effect to help understand specific results and relative advantages or shortcomings of interface techniques. We consider the following four simple target properties that may be expected to relate to performance:

Initial Target Visibility: is the number of pixels of the target visible from the subject's hand/controller start position. This can greatly affect the performance, especially when the target is substantially occluded. For example, if a target is substantially occluded by other targets, making only a very small portion of the target visible, the user has to move the input controller or should precisely point at target for selection. This movement or precise pointing can be costly and will increase the selection times. Initial target visibility is impacted by the other three properties, and so is the amount of hand motion required to aim at targets with too-low initial visibility.

Hand obstructions: is the number of objects obstructing or in between the subject's initial start position and the centre of the target object (occlusions are measured only in unprojected 3D space and are not separately measured for the two techniques). If a target is occluded by many other objects in the scene, the ray technique suffers as increased hand movement may be necessary to get around the occlusions.

Target Depth: is defined as the distance/depth of the target along the screen-normal axis (z) from the subject's initial start position.

Target Size: is defined as the size of the target, which is the length of the well log (a rectangle) in this case. Table 1 below shows these property values for each target.

Table 1. Target properties in depth sorted order

Target Number	Length of the Well/Target (in m)	Hand Obstructions	Target Depth(in m)	Initial Target Visibility
1	762	1	6.63	0
2	701.1	2	6.68	2338
3	984.5	0	7.45	14405
4	1702.6	3	7.51	43348
5	1706.9	1	7.74	0
6	4078.2	1	7.93	9730
7	2301.8	2	8.02	0
8	1507.2	1	8.40	0
9	3017.8	2	8.46	3146
10	2977.9	1	8.57	0
11	1438.1	3	8.75	0
12	1101.9	2	8.87	3404
13	1518.5	2	9.13	0
14	1982.4	4	9.35	0
15	2440.8	2	9.35	0
16	1604.8	2	9.58	0
17	1350.3	2	9.62	2131
18	2313.4	2	9.64	6978
19	2286	3	9.70	0
20	2133.6	0	9.94	5374
21	1434.7	2	10.33	0
22	3020.9	3	10.64	0
23	3169.9	3	10.87	0
24	763.5	2	10.94	0
25	2651.8	3	11.67	0

5.2 Objective Measures and Analysis

The Wilcoxon test was conducted to analyse the mean target selection time, total number of errors, mean controller translation and mean controller rotation per graphical rendering frame. The Table 2 below shows the mean, standard deviation and the improvement for the four dependent variables.

Table 2. Mean and Std. Deviation for dependent variables.

Dependent Variable	*Touch Interface Mean ± Std. deviation*	*Ray Casting Mean ± Std. deviation*	*Percentage improvement*
Target selection time	8.03 ± 3.03 sec	22.0 ± 6.89 sec	63.5
Error Count	6.6 ± 5.8	20.7 ± 10.1	68.2
Mean Controller Movement	0.08 ± 0.06 meters	2.15 ± 1.14 meters	96.2
Mean Controller Rotation	28.0 ± 9.54 radians	144.1 ± 60.5 radians	80.6

5.2.1 Target Selection Time

In our analysis for the target selection time, we included the trials that had errors. The Wilcoxon test shows the main effects for the selection technique Z (N = 18) = -3.72, p = .001.

Figure 3 shows the mean selection times for each target in depth-sorted order. The results varied widely with the ray interface. The reason for this is that various target properties such as target size, depth, occlusion and the initial target visibility affect the performance. For example, from Table 1, consider the target number 6: the mean selection time for this target using the standard ray interface is 3.3secs. Although there is one occlusion for this target and it is at a considerable depth, it being the largest target, the considerable amount of initially visible pixels makes it easier to select. On the other hand, for the target number 24: since it is a very small target and completely occluded, it takes a longer time to select this target using the ray casting technique. The selection times using the touch interface are more consistent throughout the depths in the experiment.

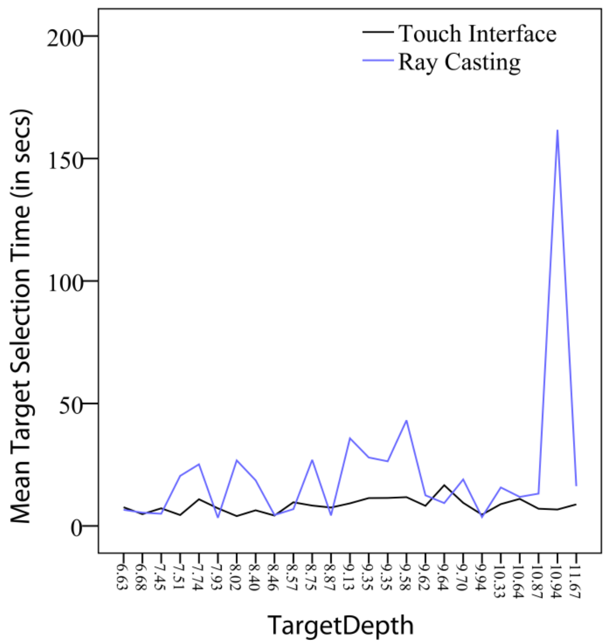

Figure 3: Mean selection times for each target in depth sorted order.

5.2.2 Error Rate

An error is defined in section 4 of this paper. Subjects made more errors in selecting small and occluded targets with the ray interface. Wilcoxon test reports the results for errors, Z (N = 18) = -3.57, p = .001. Error rate was significantly reduced using the touch interface. Figure 4 illustrates this feature.

5.2.3 Input Device Translation and Rotation

The feature of the touch device of not requiring to point at the target for selection, instead moving the thumb on the touch surface reduces precision pointing to select targets at a greater depth irrespective of their size. This significantly reduced the input device translation and rotation. The Wilcoxon test reports the results, Z (N = 18) = -3.72, p = .001 and Z (N = 18) = -3.62, p = .001, for translation and rotation respectively.

This phenomenon is illustrated in figures 5 and 6. Figure 5 shows the mean controller movement for varying target depths and Figure 6 shows the mean controller rotation for varying target depths. Mean controller movement and rotation are significantly reduced and are more consistent for the touch interface.

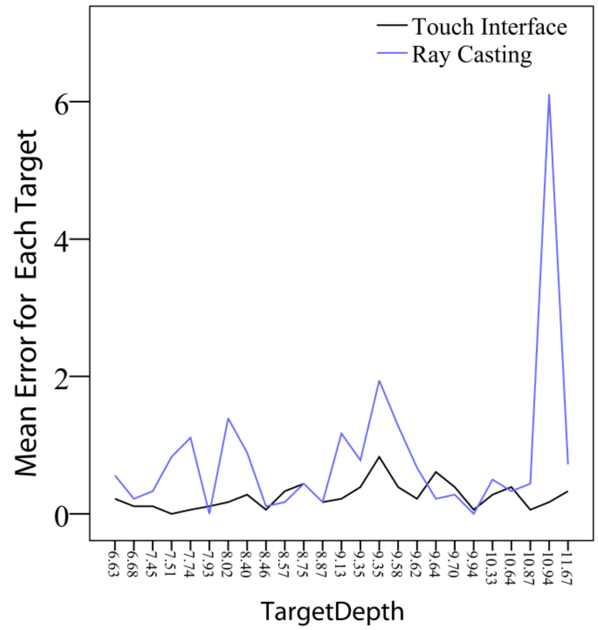

Figure 4: Mean errors for each target in depth sorted order.

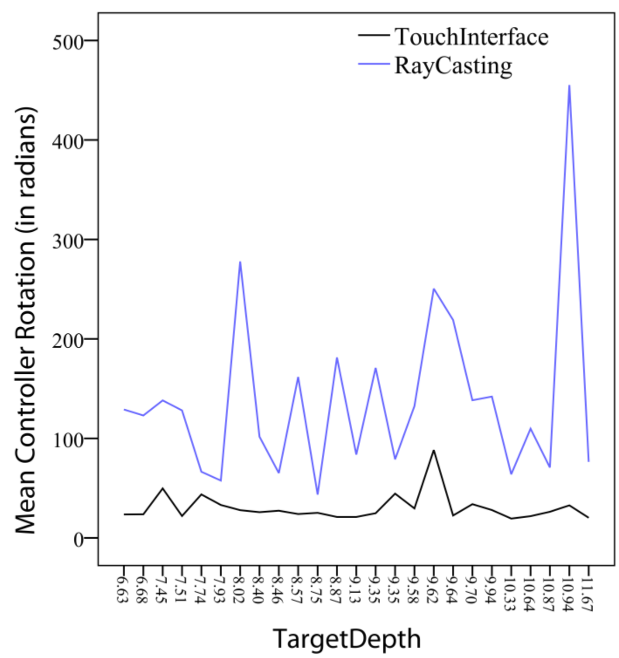

Figure 5: Mean controller rotation for varying target depths.

5.2.4 Target Property Investigation

Initial target visibility has a negative correlation with the mean selection time and the error rate. Table 3 illustrates Spearman's rho correlation to estimate the relationship between the variables for the ray interface. The negative correlation between the initial target visibility and the mean selection time per well (rho = -0.641, n = 25, p = 0.01) illustrates that as the number of visible pixels of a target increase, the mean selection time decreases.This is because, if only a very small portion of the target is visible or if the target is completely occluded, the subject has to move the input controller to highlight the target. This controller translation increases especially with the ray casting interface. Increased controller translation introduces considerable amount of error.

The most notable errors while using the touch interface occur for wells totally occluded by another nearby well (Table 4). For these targets, subjects had the problem of identifying the highlighted well on the main view due to the density – the target highlight could be misinterpreted as identifying a different well with similar projected geometry. The negative correlation between the initial target visibility and the errors per well from table 4, rho = -0.498, n = 25, p = .05 illustrates that as the number of visible pixels of a target increase, the mean selection time decreases. We believe this is not a generalizable finding, but only an artifact of main display visual design.

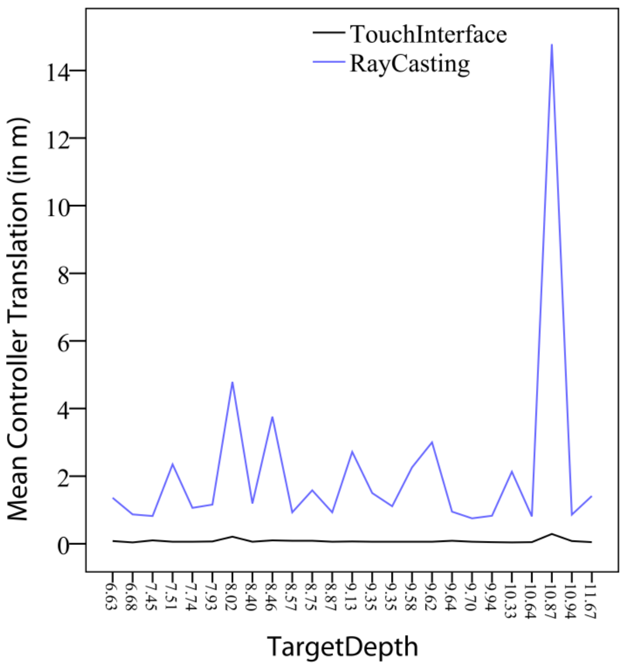

Figure 6: Mean controller movement for varying target depths.

Table 3. Correlation(rho) between variables for ray interface.

	Mean Selection Time	Incorrect Selections	Mean Controller Movement	Mean Controller Rotation
Hand Obstructions	.432*	.169	.265	-.202
Initial Target Visibility	-.641**	-.553**	-.151	0.089
*Correlation is significant at the 0.05 level(2-tailed) ** Correlation is significant at the 0.01 level(2-tailed)				

Table 4. Correlation(rho) between variables for touch interface.

	Mean Selection Time	Incorrect Selections	Mean Controller Movement	Mean Controller Rotation
Hand Obstructions	.216	.314	-.111	-.361
Initial Target Visibility	-.389	-.498*	.043	.200
*Correlation is significant at the 0.05 level(2-tailed) ** Correlation is significant at the 0.01 level(2-tailed)				

For standard ray interface hand obstructions have a positive correlation with the mean selection time. This is due to the fact that when a target is occluded by more objects, the user has to move further to find a better position to reach occluded objects. This is explained from the observations in Table 3. The positive correlation between the hand obstructions and the mean target selection time, rho = 0.432, n = 25, p = 0.05 illustrates that, as the number of obstructions increase, the selection time increases.

Length of the target and the depth has no statistically significant correlation on the dependent variable. Hence there values are not shown in Table 3 and Table 4.

5.3 Subjective Questionnaire Measures and Analysis

5.3.1 Preference Question

15 of 18 subjects reported preferring the touch interface over the standard ray interface. The most common reasons reported (10 out of the 15 subjects) are the ease of selection of targets, reduced movement, and the ability to select targets that are totally occluded. The remaining 5 out of the 15 subjects did not state any reason. 3 subjects preferred ray over the touch interface, describing it as more intuitive or straightforward.

5.3.2 Learning Question

On average, subjects reported that the touch interface took 3.3 trials to learn and the standard ray took 2.7 trials. Subjects reported that the ray was easier to learn as it is straightforward and more intuitive. Subjects reported that aiming or pointing at targets is a natural instinct and simple for the subjects.

Strain Question: 16 subjects reported that the standard ray interface had more physical strain as they had to move around to select the target objects. 1 subject stated that both techniques are equally strenuous; the ray interface required more physical movement and touch interface required more concentration. Moreover, the subject stated that they had to stand and select the targets for both techniques. 1 subject stated that the touch interface was more strenuous as the subject had to concentrate more and it was not as intuitive as ray.

Overall, subjects preferred the touch selection interface when compared to the standard ray interface.

6 Discussion

The experimental results confirm our hypotheses that the target selection time and error rate will be reduced significantly with the touch interface. Based on observations, touch interface performance was more consistent across targets, Thus, in difficult conditions, the touch interface outperforms the standard ray technique. In the standard ray interface, the increased time appears to be spent in hand or body motion to find a better position to reach occluded objects.

Although reduced, a possible reason for remaining errors with the touch interface is a subject's finger crossing the touch surface boundary. Another possibility is the "fat finger" problem. Since target objects are represented as icons on the touch display as shown in Figure 1, the subject's finger selects a very close by adjacent incorrect target when releasing the finger from the touch surface.

Although no hand base motion was required to select the target using the touch interface, the virtual ray coming out of the iPod touch can tempt the subject to point at the target when it appears, thereby resulting in some hand movement.

Observing subject behaviour with the touch interface, several of them appeared to use only thumb motion, not rotating or moving the hand in contrast to ray casting. The controller rotation for the toughest (maximum selection time) target using the touch interface – target number: 18, selection time: 16.6secs and controller rotation: 44.6 radians, is lower than the controller rotation for the easiest (minimum selection time) target using the ray interface – target number: 6, selection time: 3.3secs and controller rotation: 129 radians. This aspect of minimal hand movement is evident from the results and it suggests that the touch interface can be implemented with reduced-accuracy tracking devices or built-in sensors with no external tracking. However, the effect of orientation on the selection times and error rate must be studied further.

Based on informal observation supported by [8], we note that the touch aspect of the iPod touch was more helpful than its visual display. In the practice session, the subjects were suggested that they could try selecting targets without looking at the iPod touch. Towards the end of the practice sub-session, some subjects stated that the shift in focus from the main view was distracting and typically stopped using the iPod visuals. They preferred reduced shift in focus. Experiment trials then were done largely without looking at the iPod, with subject focused on the changing highlights revealing thumb movement in the main display.

A map overview, similar to the touch display, could also be achieved on the main display: displaying an overview of the scene on the main display and supporting standard ray pointing at the overview. The direct touch selection and more natural gesture-based interactions with touch surface have less visual clutter on the main display [8]. Additionally, we expect additional visual or mental focus shift as users would shift from wells at various depths to the overview representation.

Of the considered simple well properties, initial target visibility best matched performance for ray-based selection. However, it is too simple to consider the role of hand motions in reaching nontrivial targets. It might be extendable to consider target visibility over a range of hand positions, for example, by using a weighted average from a grid of positions. However, the aim of this experiment was to study the performance of the touch interface rather than tuning the standard ray interface.

We hope the touch display surface will further be helpful for other tasks such as annotating objects, displaying additional information about the targets, menu selection, etc.

We hope that the convenience of this design and the device will enable a walk-in and use virtual reality immersive experiences such as simultaneous dataset explorations or virtual class room training for certain disciplines for multiple.

6.1 Limitations

There are two major limitations for the touch interface study. The first one is the 2D layout of the 3D environment onto the touch surface. For this experiment, the touch interface is tested only for 3D environments that naturally lend themselves into an iconic map overview.

The second is the moderate density of the targets studied and the need to investigate denser environments. The environment density and the targets/objects size is derived from the geosciences application in which displaying hundreds of logs is not visually reasonable.

However, Prachyabrued et al. [8] talk about different projections such as world-based, controller-based, etc. to project the environment onto the touch surface. They also talk about additional gestures that the user can perform on the touch surface related to object selection and free exploration of the environment.

To select objects that are outside the scope of the default overview, the user can to drag the thumb to initiate a pan motion [8] or can do coarse initial pointing to bring the object into the overview for selection. This increases selection range and may be useful with more zoomed-in map scale, but the operations would incur additional cost.

For highly dense datasets, the overview projection scale can be made more zoomed-in to avoid the “fat finger” problem from denser objects. Selection may then involve additional pointing or panning as mentioned above.

Different overview projection types and added control from additional inputs (e.g., internal sensors) might be usable to extend the touch pad to true 3D interaction rather than 2D map selection. A possible approach is a 2-stage interaction in which the second stage selects from a different projection or dimension. For example, after a 2D selection, a user may tilt the hand to trigger a different projection for selection. In the well log application, this would support initial selection of a well followed by selection of vertical height for well “picks” that annotate critical points on a log [8]. Further work is needed to identify feasible approaches. The aim of our current experiment was to compare the basic capability of the touch surface with the standard ray interface.

7 Conclusion

While touch device techniques were previously introduced for interaction in virtual environments, in this paper we presented a formal evaluation of a touch device interaction technique for virtual environments. Touch interface performed better than a standard ray casting interface in a well-log visualization environment with substantial inter-object occlusions. From the questionnaire results, the learning required for this technique seems not very high compared to the standard ray technique, although previous work suggested it may take substantially more time to learn [8].

Experiment results suggest that the thumb movement on the touch surface enables the users to select the targets more precisely and disambiguate depths quickly with little or no hand base movement. This is important, as many 3D environments involve precise selection of virtual objects.

We see a substantial potential for using handheld touch devices for selection and exploration tasks when interacting with dense virtual environments using a low-cost tracker (or no tracking at all) and a low-cost VR display such as a 3DLP display, tiled LCD panel, etc. Further investigation is required for developing and identifying the best methods and applications.

We plan to investigate extensions to the touch interface, e.g., providing enhanced feedback to the subject about the touch point in the main display or feedback when they are at the edge of the touch surface to expand the scene with edge scrolling. We also consider comparing the touch interface with other existing selection techniques for dense virtual environments.

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