System Control, Navigation & Selection Using Off-the-Shelf Hardware for a Classroom Immersive Virtual Environment

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Abstract

In this study off-the-shelf technology is evaluated in the context of an immersive virtual environment application for use by teachers in a classroom lecture. First, four input devices are compared according to efficiency and user preferences when utilized for a system control interface. This is done in an experiment performed on high school teachers. The input devices are a pen-operated graphics tablet, a touch-operated graphics tablet, a Microsoft Kinect for hand tracking and a Nintendo Wii Nunchuk controller. The pen and tablet interface proved most efficient and preferred by the teachers and is used in evaluation of navigation and selection interfaces using the device. In a second experiment with the teachers, they significantly preferred a grabbing the air navigation interface over a joystick-inspired interface. The results show no significant preferences between a gaze directed pointing interface and an image-plane interface when evaluating selection methods. Overall, results and observations of the experiments show that the novel interfaces utilizing the pen and tablet device can be quickly understood and can support a wide variety of tasks in an immersive virtual environment.

Index Terms: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities, Evaluation/methodology; H.5.2 [Information Interfaces and Presentation]: User Interfaces—Evaluation/methodology, Input devices and strategies, User-centered design

Figure 1: The three pieces of hardware used for the system control experiment: At the top is the graphics tablet used for the pen and tablet and touch tablet interfaces, in the middle, the Kinect used for the hand tracking interface and in the bottom the Nintendo Wii Nunchuk.

1 Introduction

Equipment for immersive virtual environment (IVE) applications are getting more accessible due to the advent of off-the-shelf hardware such as the Oculus Rift [12] and Sixsense's Stem System [14]. Because of this, interest IVE is growing, both in video games and in other fields. This study examines possibilities for utilization of IVE applications for use in class lectures. This is done in collaboration with Virum Gymnasium (high school) and the interaction techniques are tested with the teachers. The request of the teachers and the goal of the study is to research and develop an IVE interface that is portable and available at a low budget. The interface should allow the teacher to perform navigation, selection and system control tasks.

The purpose of this study is to examine which interaction techniques will be best suited to teachers in the context of class lectures. The teachers will use the system to create, show and demonstrate elements of the curriculum in different environments depending on the subject. This examined in the context of illustrating subjects of astronomy, such as planetary rotation and orbits.

this study focuses solely on the usability of the interfaces when used by teachers. However, in the field of interactive applications for class lectures there are many other relevant topics, such as if the application helps students concentrate or learn the topics of the lesson, but these are not considered in this study.

Because a lot of research has already been put into natural user interactions (NUI) in 3D user interfaces (3DUI) in general, the main focus of this study is off-the-shelf technology that can be used by the teacher and students while standing in front of a class. Also, the first element of the user interface to be studied is the system control interface, seeing as the input hardware has to support tasks that may not translate well to NUI. For this four input devices are examined and compared. The device that is the most efficient and preferred by the teachers is used in further research to examine the possibilities for support of navigation and selection techniques.

The base IVE setup used for the studies is composed of a Sony HMZ-T2 head-mounted display (HMD) equipped with a wireless InertiaCube3 for head orientation tracking and a first generation Microsoft Kinect for head tracking. The four input devices tested for the system control interface are a pen and graphics tablet, a graphics tablet using touch input, the Nintendo Wii Nunchuk analog stick and Kinect for hand tracking. The hardware used for experiment is shown in Figure 1.

The paper will first describe the state of the art for this study, then two experiments will be described. The first study is on input devices for system control, the second experiment will use the results from the first to exclude input devices and thus examine navigation and selection methods for one of the input devices only. Figure 2 show the structure of the experiments.

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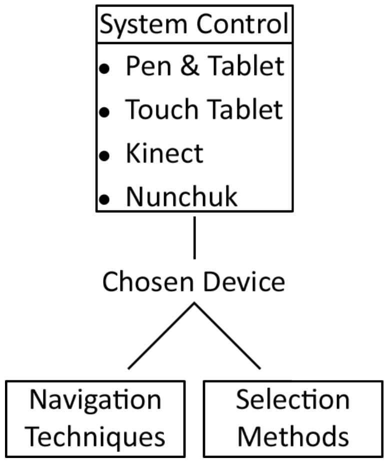

Figure 2: The flow of the research process. The system control experiment leads to the choice of the preferred interface for use in the evaluation of the navigation and selection methods.

2 Related Work

For input devices in 3DUI, degrees of freedom (DOF) are one of the most important subjects. A tracker normally captures three position values and three orientation values, which gives 6-DOF. The amount of DOF in a device, is an indication of how complex the device is.[2]
A key issue when designing interfaces for 3D applications is to choose input devices that is appropriate for the specific application. Various tasks that needs to be supported by the system must be examined in order to find or develop the most appropriate interaction technique.[2]
A survey performed by Takala et al. in 2012 among 3DUI developers, researchers and hobbyist shows that the most commonly used input devices for 3DUI are Microsoft Kinect, cameras, Wii Remotes and 6-DOF devices. Among the least utilized devices are pen operated tablets, game controllers and the Nintendo Wii Nunchuk.[15]
A pen and tablet interface increases accuracy and efficiency due to the constraint provided by the physical surface, but the downside can be that the user will tire faster because of the need to hold two physical devices [2]. Multiple studies have demonstrated the use of touch interfaces for manipulating 3D objects, either on a touchscreen [5][10][4] or in VE [16][8].
As these input devices have shown useful in IVE applications, but have yet to be compared against one another, a pen operated tablet, a touch operated tablet, the Nintendo Wii Nunchuk joystick as well a Kinect hand tracking interface are used to examine the system control interface for IVE.

The system control in 2D interfaces often use specific interaction styles such as pull-down menus, text-based command lines or tool palettes. These interaction styles have also been adapted to be used in 3DUI [2]. The UI of VE have often been based on windows, icons, menus and pointers (WIMP) interfaces, which are well known by users of desktop applications. However, placing 2D control widgets within a 3D environment can be much less natural to the user.[9]
All interaction styles may not be equally effective in all situations since users of IVE have to deal with 6-DOF and not only the 2-DOF that most desktop applications use [2]. Andries van Dam argued that this necessitated the development of what he calls "post-WIMP" UI: These are defined as interfaces that rely on, for example, gesture and speech recognition or eye, head or body tracking. Some UI are classified as being between WIMP and post-WIMP. An example of this is when designers implement system control techniques used for 2D interfaces and implements them in the VE object space.[9]
Several factors may affect the users performance in a traditional mechanical control system. These factors include; the shape and size of the controls, their visual representation and labeling, methods of selection, underlying control structures and the control-body linkage.[2]
The input control can have an effect on the user performance. Some of the things that can have an effect is the amount and the placement of buttons. Multiple buttons can allow the user more flexibility, but will also increase the risk of confusion and errors.[2]
Considering menu layout, Callahan et al.[3] compared target seek time between linear and radial menus. They argued that the advantages of decreased distance and increased target size can be seen as an effect on positioning time as parameters to Fitts' Law. The test results showed that the users operated faster with the radial menus, but the participants were almost evenly divided between the menu type concerning subjective preference. Linear and radial menu were also compared in a VR fish tank environment by Komerska and Ware [11] using a haptic pen interface. The results showed that the radial menus performed 25 % faster than the linear menus.
Due to the finding in the related studies as well as the requirements of the application and the nature of the input hardware chosen for the study, the interfaces are tested using a radial menu design.

Because the pen and tablet is a device that is used throughout all of the experiments in this paper, it is necessary to look into navigation and selection techniques in IVE's, that can be implemented with the setup. Gaze directed pointing [2] is feasible as it can be implemented using only the InertiaCube3 and the Kinect head tracking.
An alternative to the gaze directed pointing is an expanded version that lets the user move a cursor freely within the viewport using the pen and tablet. This makes the interface similar to the image-plane technique where the user marks the object desired for selection by obscuring it in the viewport with another object or cursor [13].

Grabbing the air [17] is a technique implemented by having the user drag the tip of the pen across the surface of the tablet; dragging the pen towards yourself lets you move forward and dragging it from side to side lets you move sideways relative to the direction of your gaze, it gives the user the impression of moving the world.

3 Comparison of Input Devices for System Control in IVE

This section describes the first experiment done for this study with the goal of comparing the four input devices for the use of a radial menu for system control in the IVE setup.

3.1 Preliminary Study

A preliminary study is designed to determine the most efficient physical amplitude for each of four devices, when they are to be used in a radial menu in a IVE setup. The physical amplitude in this study is the equivalent of the amplitude as it is described in Fitts' law [6]; the physical distance between the task outset and task goal. For the entire experiment the radial menu contains eight menu elements, making the equivalent of the tolerance of errors a constant. For each device, five different amplitudes are implemented, and the participants try all combinations of amplitudes and devices. This is done, to be able to eliminate the physical amplitude as a confounding variable, before comparing the devices against each other. The amplitudes are tested using tasks similar to the ones used in the

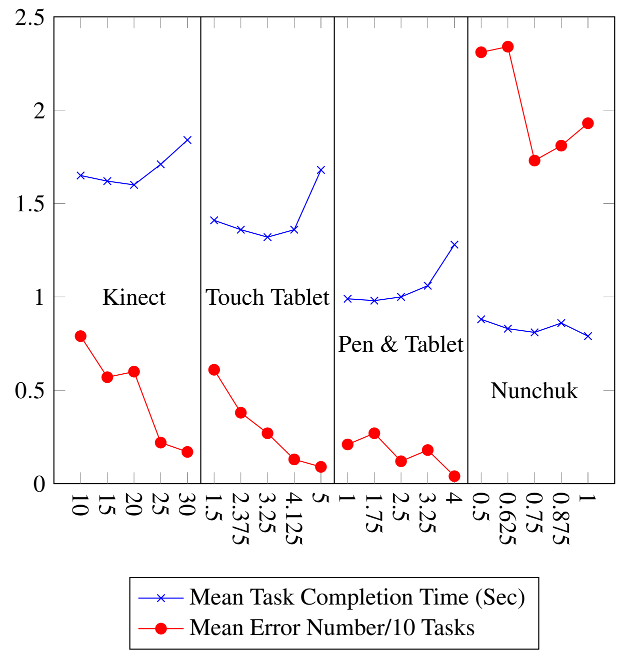

Figure 3: Mean task completion time and error rates, along the Y-axis, between the input devices and physical amplitudes, along the X-axis.

main system control experiment, and the efficiencies of the amplitudes are evaluated based on task completion time and error rates.

Figure 3 shows the mean tasks completion times and error rates for each of the physical amplitudes and the devices. From these results, it is decided to work with the following amplitudes. The amplitude used for the Nunchuk is 0.75 cm, for the Kinect 25 cm, for Pen and Tablet it is 2.5 cm and for the Touch Tablet it is 4.125 cm. Using linear regression it is determined that the results do not follow Fitts' law which states that task completion time is linearly dependent of the index of difficulty [6]. Because of this, Fitts' law is not considered for the rest of the study. The preliminary study is thoroughly described in [7].

3.2 Methods

The preliminary study resulted in one amplitude for each device, which gives this experiment four conditions. Participants try all four conditions in a counterbalanced order using a Latin square. For each condition they have 40 tasks, this gives a total of 160 tasks per participant. The tasks consist of moving the cursor to the elements in an eight-part radial menu presented in the IVE. The radial menu is shown in Figure 4. The blue elements become green as they have to be marked. They are targeted in random order, but each element is targeted five times for each device. If the participants mark the wrong element, it is considered an error and the sequence progresses to the next task. After marking each element, the center element becomes green, signaling that the cursor should be returned to the center before proceeding to the next task. The total task completion time consists of both marking the outer menu element and returning the cursor to the center. The sequence of the devices differs between the participants. The order in which they will be presented to the participants is determined using a Latin square, to avoid the results being biased by order, training and adaption to the IVE setup.
The participants are teachers at Virum Gymnasium. They are informed about the experiment beforehand and are recruited at their own initiative. Participants range from 29-66 in age, three are women and 13 men. Three participants have prior experience with IVEs.
Participants are asked to answer a pre-test questionnaire. This can be answered while another participant is performing the IVE tasks. After the system control tasks they are asked to answer a post-test questionnaire. Participants are introduced to each of the devices before they are to use the device and they are allowed to practice with the devices before beginning the tasks. In between using each device, the users are asked to rate the device according to ease of use and comfort on a scale from one to five, where five is the best. An Elgato game capture system is used to record the application. This was done from another computer than the one running the system in order to avoid decrease in performance from running both applications on one computer.

A first generation Microsoft Kinect is used for position tracking the hands and their position in relation to the head to position the cursor. The Nunchuk controller is implemented using a Mayflash Wii Classic Controller Adapter for PC USB. The cursor in the system control interface is positioned according to the absolute position of the analog stick: When the analog stick is at its resting position, the cursor is at the middle of the radial menu and when the analog stick is pushed all the way forward, the cursor is at the top of the radial menu. The pen and tablet and touch tablet interfaces utilize a Wacom Bamboo fifteen by nine centimeter graphics tablet. The pen and tablet device moves the mouse cursor to the position of the screen corresponding to the absolute position of the tip of the pen on the tablet when touching or hovering. This is used to have the cursor be at the position in relation of the center of the radial menu corresponding to the position of the tip of the pen in relation to the center of the tablet. As opposed to the pen and tablet interface, when using the tip of a finger the tablet does not track the absolute position of the finger on the surface, but rather the motion when swiping the finger across the surface. For the system control interface the touch tablet is used similarly to the pen and tablet interface, except that the user may have to swipe again if they have reached the edge of the tablet and need to move the cursor further. The interface is designed such that the user should not need to lift the fingertip from the surface of the tablet. Since this interface uses the mouse coordinates from the operating system, all mouse precision functions are disabled, so that the cursor does not move further when swiping quickly.
The environment portrayed in the IVE is that of a room with painted white brick wall and light wooden planks covering the floor and ceiling. This is to keep the environment neutral and familiar to the users while, at the same time, providing textures that for illustration of depth in the IVE. At the same time, this contrasts with the system control interface which is blue. The interface consists of a radial menu with eight menu elements in the circle as well as one in the center. The interface also has a cursor which consists of sphere which is red to contrast with the rest of the scene. The VE as well as the radial menu are shown in Figure 4.

3.3 Results

Table 1 shows a Friedman post-hoc to determine if there are any significant differences between the four conditions. Table 2 shows the error rate for each condition. Figure 5 show the rankings of usability that the participants did in the post-questionnaire and Figure 6 shows the rankings of comfort.

3.4 Analysis

The post-hoc comparison of the devices shows significant difference between all of the devices considering task completion time. The Nunchuk controller is the fastest, but it also has the largest er-

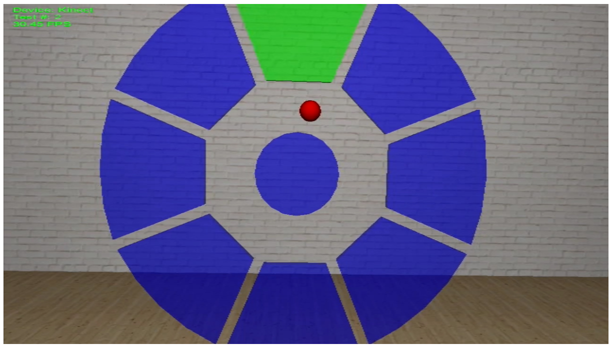

Figure 4: The eight-element radial menu with the red cursor sphere as shown in the IVE application.

Table 1: Ranking of task completion time from Friedman post-hoc, slowest conditions at the top. The letters tell the rank of the conditions. If conditions are at different ranks, there is a significant difference.

Device	Average times	Ranking
Kinect	1.88	A
Touch Tablet	1.52	B
Pen and Tablet	1.22	C
Nunchuk	1.13	D

Table 2: Ranking of error rates from Friedman post-hoc, highest error rate at the top. The letters tell the rank of the conditions. If conditions are at different ranks, there is a significant difference.

Device	Error Rate	Ranking
Nunchuk	26.41 %	A
Kinect	5.63 %	B
Pen and Tablet	5.31 %	B
Touch Tablet	1.56 %	C

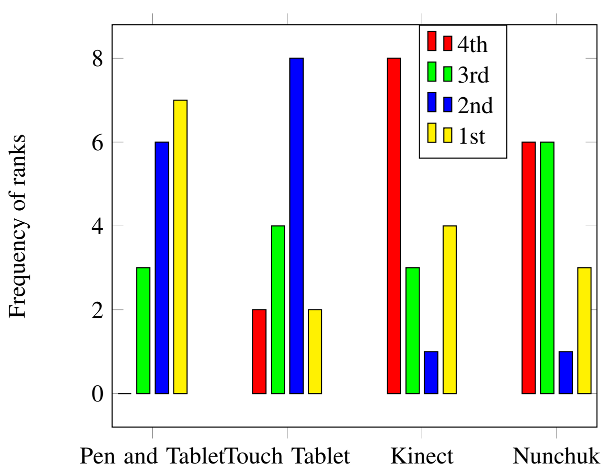

Figure 5: Usability rankings distributed by teachers among devices. The more "1st" ranks and the less "4th" ranks assigned to a device, the better it is considered among the teachers.

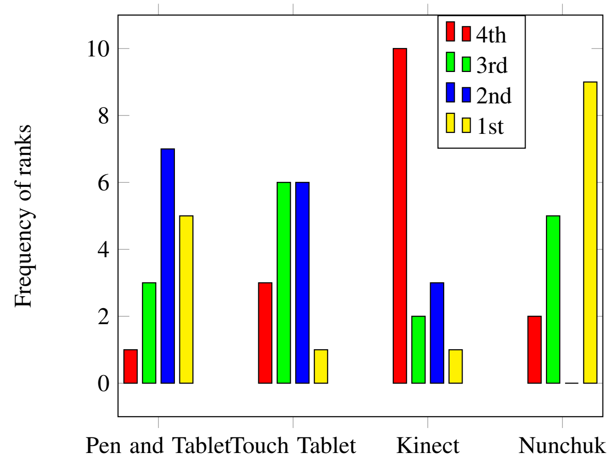

Figure 6: Comfort rankings distributed by teachers among devices. The more "1st" ranks and the less "4th" ranks assigned to a device, the better it is considered among the teachers.

ror rate. The pen and tablet is the second fastest and has the second lowest error rate. When looking at the rankings, the pen and tablet interface is among the devices that are ranked the best in both usability and comfort. Because of these results, as well as comments from the teachers, the pen and tablet interface is chosen for further research. The second experiment with focus on navigation and selection is done using this device.

4 Examination of Navigation & Selection Techniques

This experiment is conducted to examine selection and navigation techniques for the chosen interaction technology. Two methods for both selection and navigation are tested.

4.1 Preliminary Study

A preliminary study was attempted to examine efficiency of the selection methods according to task completion time and error rate, but due to severe drifting from the wireless Inertiacube3 it is not possible to compare the two methods on efficiency. Because of this, it is decided that both selection and navigation are evaluated based on user preference and comments alone.

4.2 Methods

The navigation methods compared in this experiment are the grabbing the air technique, where the user drags the tip of the pen across the tablet surface to drag himself around the VE, and a technique inspired by a joystick, where the user positions the cursor in relation to the center of a circle, determining the movement direction and velocity. The joystick interface is illustrated in Figure 8. Both navigation interfaces let the user move along a vertical plane rather than the horizontal plane by holding down a button on the pen while moving. A set of arrows rendered in 3D in the viewport of the user indicates the movement directions.

These interfaces are tested using two modes of navigation: One mode lets the user move directly in the direction of the gaze, meaning that moving forward while looking upwards or downwards moves the user up and down in VE world space. The second mode locks the user's movement to the active plane. In this mode only the gaze direction around the vertical world axis affects the movement direction of the user. This is illustrated in Figure 9.

Two techniques are tested for the selection interface. The first is gaze directed pointing, where a red crosshair is placed in the center of the viewport to help aim. For triggering the selection with this interface the user must tab the tablet with the tip of the pen. For the second technique the gaze based pointing is an expanded version that lets the user move the cursor freely within the viewport using the pen and tablet. In this case the user marks the object with the cursor and selects it by tapping the tablet. The selection interfaces are illustrated in Figure 10.

In the experiment, three factors are tested individually. The first factor is the navigation technique with two levels; grabbing the air and joystick mode. The second factor is the mode of navigation with two levels; plane bound and gaze directed steering. The last factor is the selection technique with two levels; gaze directed pointing and image-plane selection. The factors are not fully crossed in the experiment.
First the two navigation techniques are tested with plane bound navigation, after which the participant chooses the preferred technique. After choosing the preferred technique, the users try it with gaze directed movement. Participants have to complete three tasks using each interaction technique. The tasks for the navigation techniques and the gaze directed steering technique are the same. Here the users are to move between certain pillars that are placed on a platform in the VE. First they have to move between two pillars along the edge of the platform, then they are told to move diagonal across the platform to the pillar across from the one they were next to. The last task is to move up through the ceiling.
The tasks for the selection methods are to select three planets in a sequence placed in the VE. The planets and the VE used for the experiments are shown in Figure 7. These tasks are completed twice, once for each of the selection methods. Before the tasks, the participants will be allowed time to try and adjust to the interaction method they are about to use. The techniques are tried in counterbalanced order to avoid bias in the results. When all of the tasks are completed, the participant will have chosen the preferred method of navigation, mode of navigation and selection method.
A semi-structured interview is used to give the participants the possibility to give more in depth descriptions of their experience with the system.

The participants for this experiment are all people with teaching experience. 17 participants are used in this experiment. 13 of the participants are teachers at Virum Gymnasium while four are lecturers at Aalborg University. One of the teachers is a woman, and ages range from 30 to 53. Of the teachers participants only 12 will be part of the statistics since the last did not finish the experiment due to motion sickness. The last 4 participants are from Aalborg University and their ages range between 28 and 48.

4.3 Results

Figure 11 shows the choice sequence of each of the participants, giving an impression of the tendencies and allows us to see sequences that stand out from the rest. Table 3 shows p-values for statistical analyses of user choices in interfaces as well as significant connection between choices of interfaces. The data is separated into two groups; one group is the teachers at Virum Gymnasium and the other is all of the participants. This is done because the results from the teachers show some tendencies that are different from the results where the lecturers are included. This mainly affects the tendencies for selection techniques.

Ten participants experienced discomfort after using the IVE system. Of these 10, 6 experienced the displeasure as a result of pain from wearing the HMD. One got motion sickness and had to leave the test early and the rest experienced slight dizziness and irritation in the eyes.
When asking about preference to navigation and selection tech-

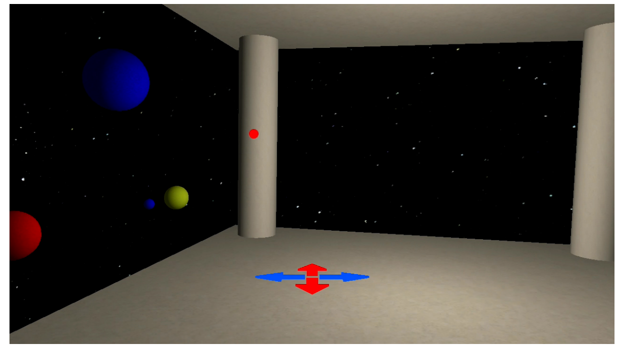

Figure 7: The VE used for evalution of the navigation and selection methods. The spheres at the left is the objects used for the selection tasks.

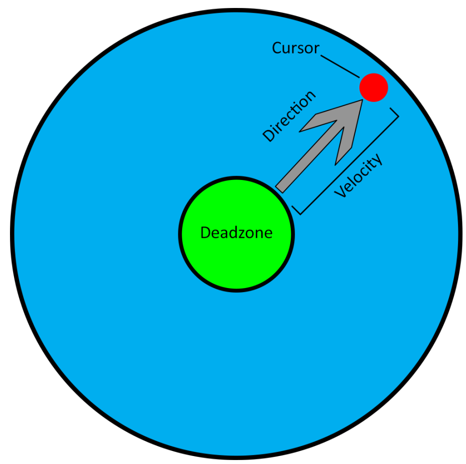

Figure 8: The GUI for the joystick navigation technique, illustrating the movement direction and velocity according to the cursor position in relation to the center.

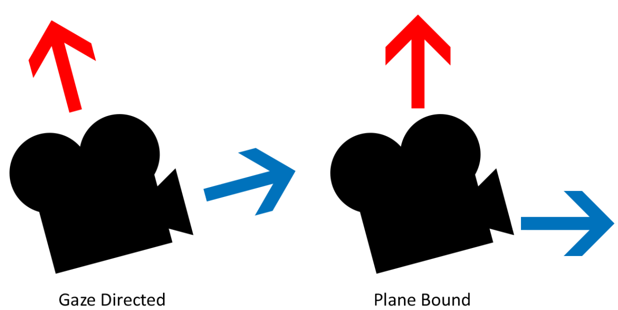

Figure 9: When the plane bound navigation is engaged the user moves along that plane regardless of gaze pitch and roll. The blue arrows illustrate the movement direction when moving along the horizontal plane and the red arrows illustrate movement along the vertical plane.

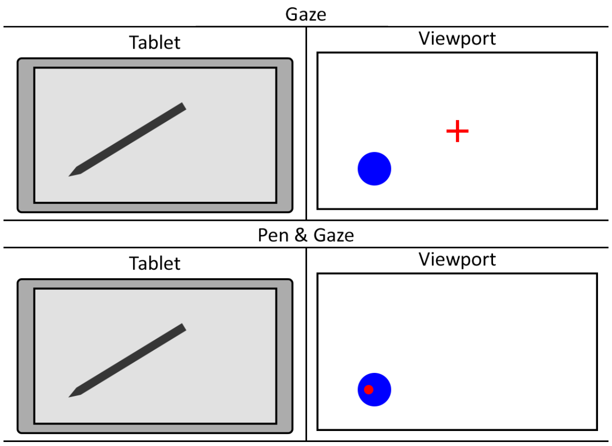

Figure 10: The selection interfaces. Using the gaze directed pointing gives a static crosshair in the middle of the viewport. The image-plane technique allows for pointing the pen to a position on the tablet to positions the red cursor in the corresponding position in the viewport.

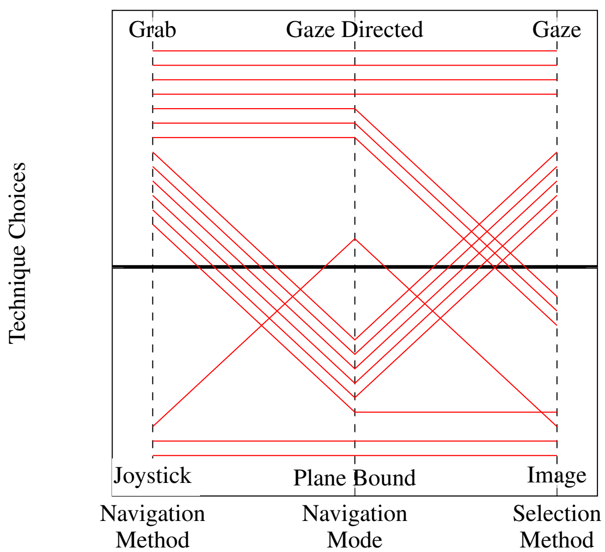

Figure 11: Parallel coordinate plot of the choices of interaction techniques throughout the experiment. A red line crossing a dotted line above the black line means that the user chose either the grabbing the air technique, gaze directed navigation or gaze directed pointing. Crossing below the black line means that the user chose either the joystick navigation technique, the plane bound navigation mode or the image-plane selection method.

Table 3: P-values for Binom tests and Fisher tests for participants' choices of interfaces and interaction techniques.

Subjects	**Teachers**		**All**	
Techniques	**Distribution**	**P-value**	**Distribution**	**P-value**
Grabbing the air/Joystick	9-3	0.146	13-3	0.02127
Plane bound/Gaze directed	8-4	0.3877	8-8	1
Gaze/Gaze & pen	7-5	0.7744	9-7	0.8036
Choice Combinations	**P-value**		**P-value**	
Navigation/Flight	1		1	
Navigation/Selection	0.04545		0.0625	
Navigation Mode/Selection	1		1	

niques, most users based their decisions on what they thought the most logical and intuitive to use. Several users thought that there was little difference between the two selection techniques. Some participants described that they would have preferred the selection technique with both gaze and pen if they did not risk deselecting by error because, as it was difficult to keep hovering without hitting the tablet with the pen. For further research it would be beneficial to implement these methods differently in order to avoid this problem. A few had trouble remembering how to use the controls while completing the tasks, but all of those said that it was something they would learn quickly through practice.
Their general impression of the system was good. Many said that it worked fine and it was simple and easy to use. One participant said that he forgot the discomfort of the HMD while working in the VE. Several answered that it was easy to navigate look around the VE. A few noticed the problems with drift from the wireless Inertiacube3. One participant described the system as weird and unfamiliar and another described it as out of focus.

4.4 Analysis

Figure 11 shows grouping of participants when it comes to their interfaces preferences, eventhough the results in Table 3 show little significant correlations between choices.
The p-values from Table 3 shows that there is a significant number of participants who chooses the grabbing the air technique. When looking at the results from the teachers at Virum Gymnasium, there is a significant result when looking at the combinations of choices of navigation and selection technique. This shows that there may be a connection between the chosen navigation technique and the chosen selection technique, but this is only when looking at the teachers on their own.
This experiment has thus given clear results for the navigation technique, where grabbing the air technique is the most preferred by the users. When looking at the selection techniques tested, there is no significant preference based on these test results. This should be examined further. It would be beneficial to iterate on the image-plane selection technique to eliminate the risk of errors. A solution could be to use the button on the pen instead of tapping the pen on the tablet. This way the user can move the pen on the tablet instead of hovering it above.

5 Conclusion

In this study, three topics have been examined.

- What is the most efficient and preferable WIMP-based system control interface for an IVE for use by teachers in a classroom context using off-the-shelf input hardware?
- Which of two navigation technique in VE using the pen and tablet interface is the most preferred by the users; grabbing the air or joystick mode?
- Which of two selection methods using the pen and tablet interface is the most preferred by the users; gaze directed pointing or gaze directed pointing combined with image-plane selection?

To be able to answer the first research question four devices were chosen to be part of the research; the Microsoft Kinect for hand tracking, a Nintendo Wii Nunchuk controller, graphics tablet operated using a pen as well as touch. The first experiment was done to be able to compare the devices with each other by determining the most efficient physical amplitude for each of the devices in order to compare them against one another with the second test using the target group. Based on the efficiency of the devices based on task completion time and error rates as well as user preferences, the following has been concluded:

- The pen and tablet is the most efficient and preferred input device for system control in IVE when used by teachers.

For the second and third questions the interaction methods were compared and based on user choices and comments the following has been concluded.

- A significant number of teachers prefer the grabbing the air navigation technique over the joystick technique.
- At this point there is no significant preference between gaze directed pointing and image-plane selection for teachers.
- There are no significant connections between choices of navigation techniques and choices of selection techniques.

In addition to these conclusions the study shows the possibilities of the pen and tablet interface as a viable input device for IVE, as it has proven to be able support a wide variety of interaction task. Also, regardless of interaction techniques and user preferences, most test participants were able to pick it up and use it very quickly.

It should be considered that the sample sizes for the experiments in this study have been small considering the population of teachers that could be interested in the system. Also, the test subjects have been recruited from one school and one university department. It is necessary to test on larger group of teachers from various schools. Also, the preliminary studies have not been performed on teachers, but on people of a different age range. This is not expected to have an effect on the results, but it is a possibility.

6 Future work

Before a finished IVE application for use in class lectures is to be used, there are additional subjects to examine.
The examinations of selection techniques did not show significant preferences, so this should be examined further with a larger sample size and a polished image-plane selection method to eliminate erroneous deselection of objects.
One of the users suggested the ability of creating the virtual environments on a desktop computer instead of always setting up the equipment and using the VE.
Also important to examine is how users are affected by motion sickness when they do not control the navigation themselves, as it is the intention that navigation of the student is to be controlled by the teacher.
An additional relevant subject to consider is the educational value of IVE's for class lectures: Is it beneficial for the students' understanding of the subjects, or will it act as a distraction? Also, research should be done in the context of a lecture with both teachers and students.
It should also be examined how to best allow for non-verbal communication between teachers and students wearing the HMDs, allowing the students to mark if they have questions during a lecture. Possible solutions include webcam feed of the classroom for the teacher or a key operated interface for the students. Relevant for this is research in collaborative VE systems such as [1].
Many participants find the HMD uncomfortable after wearing it for duration of the experiments. A more ergonomic HMD would be a solution to this problem.
Placement and size of the radial menu should also be examined, as well as whether or not the menu should be visible at all times or if it should be activated.

Acknowledgment

The authors would like to thank the supervisor of the project, Rasmus Stenholt. Thanks to the teachers at Virum Gymnasium with special thanks to Jens Malmquist who was our contact at the school. Also, thanks to students and teachers from Medialogy at Aalborg University, who participated in experiments.

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