

Evaluating Devices and Navigation Tools in 3D Environments

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Abstract. 3D environments have been used in many applications. Besides the use of keyboard and mouse, best suited for desktop environments, other devices emerged for specific use in immersive environments. The lack of standardization in the use and in the control mapping of these devices makes the design task more challenging. We performed an exploratory study involving beginners and advanced users in the use of three devices in 3D environments: Keyboard-Mouse, Wiimote and Flystick. The navigation in this kind of environment is done through three tools: Fly, Examine and Walk. The study results showed how the interaction in virtual reality environments is affected by the navigation mechanism, the device, and the user's previous experience. The results may be used to inform the future design of virtual reality environments.

Keywords: 3D environments, evaluation, navigation tools, user experience.

1 Introduction

3D environments have been increasingly used in several applications. In order to make the navigation easier, many devices specific to immersive environments emerged, to substitute or complement the keyboard and mouse, which are best suited for desktop environments. The lack of conventions in the control mapping of these devices makes the design of 3D environments quite challenging.

In addition to the challenge related to the physical use of these devices, we have to face challenges related to the interaction based on 3D interfaces, which are more complex than those based on WIMP bi-dimensional interfaces. This happens because the latter offers a synthetic view of interaction possibilities, progressively brought to the user through a clearly planned and understandable sequence of windows and panels. Because of a host of established conventions, the user generally knows which sequences of actions perform some wanted operation. Equivalent results may be obtained in different ways involving different interaction styles, but the number of alternative behaviors is usually small, *e.g.*, menu selection vs. keyboard shortcuts. Conversely, the interaction in 3D environments involves an exploratory approach and requires typical real world operations like moving, navigating around objects, and so on. For each step, there are several actions and many ways of alternating movements during the interaction with these devices [2].

Another issue that goes beyond the interface and the devices mapping is related to the user's understanding while navigating in a 3D environment. In order to navigate in a satisfactory way, some aspects have to be considered, such as the sense of orientation. Zhai et al. [9] talk about the orientation sense as an important point, describing users who are "out of their goals" or who "lose their location". Furthermore, Robertson et al. [5] point out the difficulty of "having the sense about where you are or knowing what is behind you". This can clearly affect the ability of finding information and performing the task efficiently.

With the goal of investigating the challenges related to the navigation in 3D environments, we did a study with beginner and advanced users during the use of three devices: Keyboard-Mouse, Wiimote and Flystick, relating their use with three widely used navigation mechanisms: Fly (on the scene), Examine (the scene around a specified point) and Walk (in a surface). The way the user deals with these mechanisms depends on the chosen interaction device. The results of this study showed how the use of the devices, together with the users' experience and the knowledge and use of the three navigation mechanisms affect the interaction in virtual reality environments. Furthermore, we identified problems and obtained suggestions from the participants that may be useful for the design of 3D applications that make use of these devices and tools.

2 The LVRL Framework

LVRL (*Lightweight Virtual Reality Libraries*) is a non-intrusive framework that allows the conversion of desktop applications in immersive ones, in a way that both types of environments (desktop and immersive) : in a way that both type of environments can be interchanged at execution time. Regarding the output, the difference between an immersive application and a desktop application is related to the fact that the first application supports multiple video outputs from distinct viewpoints [7]. Regarding the input, the main difference between these applications is that, in immersive environments, one should use "non-conventional" interaction devices and techniques.

Three navigation mechanisms were used to evaluate the framework in a 3D environment: Fly, Examine and Walk. *Fly* allows the camera to fly through the scene at a given speed and the user to freely exploit the environment. *Examine* allows an object or location in the scene to be inspected. Its operation consists of rotating the camera around a point of interest, called rotation center or pivot, also allowing to zoom in on this object. To do so, it is necessary to first choose the object that will be the pivot (number 4 in Fig. 1). If the pivot is poorly specified, the resulting behavior is likely to confuse the user [3]. *Walk* allows the user to walk around the scene. It is similar to Fly, but now gravity applies, giving the feeling of really walking on a surface. During navigation, it is possible to set the speed of Fly and Walk.

The investigated environment (Fig. 1) has a toolbar with icons corresponding to the three kinds of navigation (identified by the number 2 in the image): Fly, Examine and Walk, to the pivot setting (number 3) and other options not addressed in our study. The option to go back to the initial position of the scene is located in the pull-down

menu (File → Reset). Using only Keyboard-Mouse, users can navigate and directly manipulate objects at the user interface and the camera. With the other devices, these operations are done through dedicated buttons in the device.

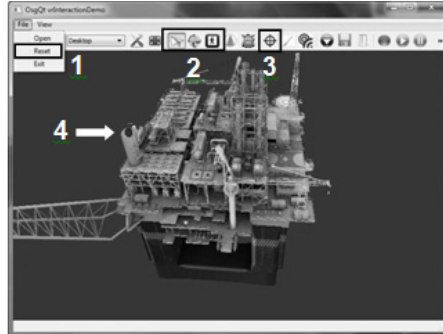


Fig. 1. The environment user interface

3 Evaluated Devices

We evaluated three kinds of devices in our study. The first one is **Keyboard-Mouse**, whose mapping to the navigation mechanisms is described in Table 1.

Table 1. Keyboard-mouse mapping

		Fly	Walk	Examine
Key-board	Arrows	To move to front, back, left, right		-
	A	To move to up	-	-
	Z	To move to down	-	-
Mouse	Scroll	Speed control		Zoom
	Click	Keeping the button pressed and dragging the mouse, you orient the movement direction.		To select pivot
	Drag			Camera rotation around the pivot

The second device is **Wiimote**, a 3D input device of Nintendo Wii game console. It brings a series of buttons to communicate with the console and, to detect movement, it has an accelerometer and an infrared sensor. Wiimote became a device used by 3D application developers because it requires a single Bluetooth receptor.

In the LVRL framework, Wiimote movements are captured only with the accelerometer. In addition to the device buttons, only two movements are supported: “pitch”, which is the rotation movement upon the transversal axis; and “roll”, which is the rotation movement upon the longitudinal axis. However, there is a movement, called “yaw”, which is not adopted with Wiimote in the LVRL framework, due to the lack of support for the infrared sensor, in charge of recognizing this movement. Table 2 summarizes the Wiimote–framework mappings, and Fig. 2a shows the Wiimote and the layout of its buttons.

Table 2. Wiimote mapping

		Fly	Walk	Examine
Buttons	I	To shift the navigation mode		
	Home	Camera initial position		
	Arrows	To move to front, back, left, right	Camera rotation around the pivot	
	A	-	To set and select pivot	
	+ and -	Speed control	Zoom	
Pitch and Roll		To orient the movement direction		-

Table 3. Flystick mapping

		Fly	Examine	Walk	
Buttons	Analogic	Move	To move to front, back, left, right	Camera rotation around the pivot	As in Fly
		Click	-	Set and select pivot	-
	B1	Camera initial position			
	B2 and B3	Speed control	Zoom	As in Fly	
	B4	To shift the navigation mode			
	Pitch, Roll and Yaw	To orient of the movement direction	-	As in Fly	

The third device evaluated is **Flystick**, a wireless interaction device developed by ART Tracking [1] for virtual reality applications. It has six buttons and an analogic directional button. The Flystick movement recognition is done through two infrared cameras placed in opposite sides, one in the right and the other one in the left of the projection. The orientation of movement direction, in Fly and Walk modes, depends on the movement of the hand when the device trigger is pressed. Flystick supports the pitch, roll and yaw movements. Table 3 presents the mapping of Flystick buttons. As seen in Fig. 3, Flystick has four non-labeled buttons aligned below and around the directional one. In the table, from left to right, they are identified as B(1-4).



Fig. 2. (a) Wiimote device. (b) Flystick device.

4 User Study: Participants and Procedures

We conducted an exploratory study with users, aiming to investigate the users’ perception of the LVRL-device mappings and to collect the users’ opinions about the

three devices, following a qualitative research approach [4]. In our study, potential users of an application developed with the LVRL framework navigated through a 3D model of an oil platform, where they should execute the proposed task. Our main objective was to investigate the use of three devices, considering the mapping of the different controls determined by the framework developers. We observed how people interact with the involved devices and how they understand the control mappings. In addition, we tried to identify their difficulties, preferences and suggestions for improvement of the devices' use and navigation mechanisms.

We determined the users' profile based on the framework features involved in this research. Six right-handed participants were recruited, categorized in two profiles: beginner and advanced. The participants are identified by PB1, PB2 and PB3 for beginners and PA1, PA2 and PA3 for advanced ones. The beginners were 26, 35 and 36-year old women who did not have previous experience with devices in 3D environments. The advanced users were 25, 27 and 31-year old men who use 3D applications at least once a day. All of them had previous experience with 3D visualization and 3D games. All of them had used game devices such as Wiimote, Joystick and Kinect at least once. PA3 was the only who had used the Flystick beforehand.

The test was divided in five stages: 1) introduction and application of pre-test questionnaire; 2) explanation about the framework and presentation about the device mapping; 3) training with the device; 4) task execution; 5) semi-structured interview.

The users executed the same task using Keyboard-Mouse, Wiimote and Flystick. In the proposed task, they should navigate on an oil platform (as seen on Fig. 1) using the navigation tools: Fly, Walk and Examine, according to the presented instructions. In each step of the task we suggested them to use a specific tool, but they could use the preferred one. They executed the task using each device separately following a pre-determined order. The order of the used devices was modified between the users to reduce learning effects in the study results. After the execution of each task, a brief semi-structured interview was conducted to capture the user's opinion about the mapping of the used device.

5 User Study: Results Discussion

5.1 Navigation Tools

We present data related to the users' interpretation, use and preference regarding the three navigation tools. The evidences reported here can be generalized to the tool concepts themselves. Even when the issue occurred during the use of a specific device, we have noticed that it is also applicable to the other devices.

Fly Mode. This navigation mode was, in general, understood by the participants. It was also one of the most used, due to its flexible navigation. Among the beginners, we noticed a frequent use of Fly to recover from falls during the Walk mode. Some problems occurred during Fly. For example, PB1 tried to use zoom, available only in Examine. PB2 tried to "spin" around a point in the platform with Fly, instead of the more recommended tool, Examine. This participant thought that Examine was just to

select the pivot and then, to turn around the vision, it would be necessary to use Fly. Regarding the advanced participants, PA1 complained about this mode. He would like to see options such as zoom in and zoom out for Fly, as it is possible with Examine.

Examine Mode. Although Examine has a very specific function and fewer handling options in comparison with the other two modes, both user groups had some difficulties in using it. All problems identified were related to marking the pivot. PB2 and PA1 had trouble recognizing that the object was already marked as pivot. In other words, they believed that, whenever they used Examine, it would be necessary to mark the pivot, when in fact, you can use Examine using a previously defined pivot.

Walk Mode. This navigation tool presented the greatest difficulty to both groups. The main reason for this is the peculiar feature of the Walk Mode: locomotion on surfaces only. When the user approaches an “open” area, he suffers the effects of gravity and starts to fall until he or she finds another surface. This feature, though realistic, caused ample frustration among participants. Because of this problem, during task performance, although recommended to use Walk, participants preferred to repeatedly use Fly. We could then identify three common situations that caused falls during Walk: (1) When changing from Examine to Fly, the users must pass by Walk. If they were not on a surface, the user fell. The way to overcome this problem was to make trading so quickly so as not to give time for the selection of Walk to take effect. (2) There is a lack of peripheral vision in Walk, so it is hard to see the boundary surfaces in some situations, especially at the sides, since usually the camera placement is forward. (3) There was a difficulty in understanding what a safe surface is. While in Fly or Examine mode, when participants changed to Walk, they sometimes did not realize that there was no surface directly below them.

PB3 gave us an interesting suggestion to work around this falling problem: enable Walk mode only when you are in a favorable position above a safe surface.

5.2 Interaction Devices

In this section we present and discuss data that specifically address each device, considering issues related to handling and mapping.

Keyboard-Mouse. Most participants reported problems related to the sensitivity of the devices. In all cases, the movements carried out using the mouse or keys resulted in very fast movements on the display, thereby exposing the high sensitivity of this device. A consequence of this problem was that PB1 and PB2 strongly avoided using the mouse. They were trying to get where they wanted by using only the arrow keys. They used the mouse only in Examine (which has no associated function on the keyboard). However, unlike them, PB3, even having reported the problem of sensitivity, used the mouse quite often. PA2 also complained about the mouse high sensitivity.

PB1 and PB2 reported that they liked to use Examine with Keyboard-Mouse. We attribute this preference mainly because the pivot was marked with just the click of the mouse, unlike other devices, where it is selected with a virtual ray pointed in the screen. Both users stated that the use of the mouse was easier only with Examine. PA1 was pleased with the mouse sensitivity, and did not need to control the speed any

time, neither in Walk nor Fly. The advanced participants, in general, did not show as many problems as the beginners. PA1 and PA2, for example, performed the task very fast, with only a very brief navigation. PA1 also dismissed the initial training time, starting directly to the task. He, after all, considered that he had an “obvious” facility using mouse and keyboard in 3D environments.

Regarding the mapping of the controls on this device, we have seen problems related mainly to the use of the mouse wheel (used to control the speed). PB1, PB2 and PA2 did not like this mapping. PB1 and PB2 agreed that this speed control was the worst problem of using Fly with Keyboard-Mouse. Another problem observed was that PB2 thought she could rotate the camera using the directional keypad. After a while, she realized that it was the mouse that controlled the camera. These participants felt bad having to use the mouse and keyboard at the same time. They would like to do everything on the keyboard. PB2 explained that for navigation tools Fly and Walk, she preferred directional commands that could be mapped to the far left of the keyboard, rather than the arrows. Thus, it would be best to use your left hand to set the direction of movement. She also suggested that the directional arrows were used to perform the movement of the camera, originally mapped to the mouse.

PA1 and PA2, who had experience with keyboard and mouse in 3D environments and / or games, suggested that the functions of the directional arrows should be mapped onto the keys “W”, “A”, “S”, “D”, which is a common pattern in computer games. PA2 also suggested that the functions keys could be kept to those who preferred to use that way. Another option was also to replicate the functions of the mouse on the arrows, for those who wanted to do everything from the keyboard.

Wiimote. While PB1, PA1 and PA2 used only the right hand to handle the device; PB2, PB3 and PA3 preferred to use both hands to change the navigation mode and to increase or to reduce speed, as a way to streamline and facilitate their interaction with the device.

Among all participants, the most recurrent problem was the limitation imposed by the device relative to movements to the left and to the right. In this case, participants should rotate the control to the sides (roll, previously discussed), while the upward and downward motion was to raise the control to these directions (pitch). In many situations, PB1 and PB2 moved the hand sideways (yaw) instead of rotating it (roll). PA2, PB3 and PA3 said it was more comfortable and natural moving side to side (like in Flystick) instead of rotating the control. Moreover, PA2 explained that the turning motion had little precision, which threatened his locomotion.

Another common problem was the lack of a rest position during Walk. Even if the participant did not move the control, the camera did small and constant movements and caused unwanted displacements. Because of this, PB3 used both hands few times to help the movement. To solve this problem, PA1 suggested using the trigger to “lock” movement. PA1 reported that he did not consider practical the speed control of Wiimote and PB1 reported that she avoided using this function. She would prefer going slowly, feeling control of the situation because she was afraid of getting lost.

The participant PB1 had difficulty to select the pivot and she reported there was no precision in the Wiimote movement. Except for selecting the pivot, she was satisfied

with using Examine. PB2 suggested that the exchange of navigation tools could be performed by the button “B” (trigger) rather than with the button “1”. According to the participant, this suggestion was based on the location and accessibility of buttons (Fig. 2). Some participants reported a problem related to the shift of these tools by a single button on a cyclical basis, mainly due to the obligatory passage by Walk when this was not the goal. PB1 and PB3 suggested that were used different buttons for navigating to the right and to the left among the navigation tools. PA1 and PA2 suggested that Walk could be activated by a separated button.

Flystick. The beginners demonstrated greater acceptance of the Flystick device. In some occasions, PB1 highlighted its ease of use; she liked the ergonomic characteristics of the device and the way to handle it. She said: “My perception is that I can map better my intention with the movement of this device”. PB2 also liked the good control response. PB1 and PB3 also praised the analog control device.

Some participants reported problems related to the sensitivity of the hand movement (camera control) and of the analogic motion control (steering control). About the first case, PB3 and PA2 found that the sensitivity of the device was low, *i.e.*, the navigation was slow and imprecise. PB3 thought the camera rotated very slowly when compared to the physical movement that the device performed. PA2 used to raise the control abruptly and maintained it pointing upwards, while on the scene the camera lifted slowly. On the analogic control, PA1 and PA3 considered that their sensitivity was high during navigation in the Examine and Walk mode, respectively.

In addition, PA2 explained that using Flystick it was harder to turn corners during Walk and he would prefer to go through the middle of the platform to avoid falling.

When we asked PA3 what he thought most difficult to do with Flystick, he answered: “The hardest part was hitting the Walk mode, because you have the freedom to point to where you want to go is great, except that when you apply speed it becomes too fast. Sometimes you lose a bit of control”. Still regarding Walk, PA1 complained about not being able to lift his head up to look up. One of the few complaints about the Flystick mapping among the beginners was related to the combined use of hand movement to control the camera with the trigger activation: the camera only moved when the trigger was pressed. In some cases, this requirement meant that the participants moved the hand vigorously without viewing any result on the screen. In order to change the cyclic shifting between navigation modes, PB3 and PA1 suggested holding the button on the far right to navigate to the right and include the leftmost button to navigate to the left. PA2 suggested using a separate button for Walk, just as he had suggested for Wiimote. Regarding mapping suggestions, PA2 was emphatic: “So, my suggestion is to give it up”. He really did not like the handling of the device, but he had no complaints about the mapping.

Comparing the Three Devices. Regarding Keyboard-Mouse, PA1 considered this device “lighter” than Flystick. PB3 said she preferred Keyboard-Mouse because “he was used to it”. She said: “Well, I have more ease in using keyboard and mouse. I’m not used to playing or doing anything with that (*pointing to Flystick*)”. For PA3, if he did not have the option of keyboard and mouse, he would choose Flystick.

Considering Wiimote, PB2 and PB3 thought the speed control in this device was better than in the mouse. PA3 considered the speed control better in Wiimote than in Flystick. For PA1, Wiimote's motion and response is better than Flystick's. In contrast, he thought the accuracy in Wiimote worse than in Flystick due to the absence of yaw movement. He added that Wiimote is ergonomically worse than in Flystick. PB1 also cited this relation, by adding that the former had no advantage over the latter.

With respect to Flystick, among the beginners, this device has more advantages than the others. PB3, for example, said that the mapping of Flystick buttons was better than in Wiimote. The participant expressed her admiration for Flystick: "I really liked this analogic control. I found it much easier. It arrives fast where you want." PB2 stated that the camera movement in Flystick is better than in Keyboard-Mouse. PA3 said the speed control on Wiimote was better, but moving with Flystick was more natural. PA2 demonstrated a negative opinion regarding Flystick. When starting the test, he said it was very odd the use of Flystick and very different from Wiimote. Comparing Flystick with Wiimote, he recognized that the first one does not have the problem of moving the camera during Walk. But this problem was smaller than the bad movement of Flystick. He said: "The learning curve (of Flystick) is much higher than the other two".

In order to improve the highlighted viewing of preferences in this section, jointly with previously pointed evidences, Table 4 presents a global ranking of preferred devices for each participant, and indicates the use order of each device to facilitate comparison (the preferred device received score 1). The table reveals an overall rejection of Wiimote, which was not ranked last only by PA2. Keyboard-Mouse proved to be the preferred device among advanced participants. We believe this was due to the fact that they are used to it in 3D applications.

Flystick was in third place only in one case, and it was the preferred among beginners. We attribute this behavior to the Flystick particular feature of responding in the screen to real movements of the hand. The camera should be positioned, in the visualization, to where Flystick is pointed. This mapping between the physical and virtual behavior is much more direct than the other two devices.

Table 4. Use and preference order

	Keyboard-Mouse		Wiimote		Flystick	
	U	P	U	P	U	P
PB1	3	2	1	3	2	1
PB2	2	2	3	3	1	1
PB3	1	1	2	3	3	2
PA1	2	1	3	3	1	2
PA2	1	1	2	2	3	3
PA3	3	1	1	3	2	2

U = Use Order, P = Preference Order

6 Final Considerations

The lack of standardization in the use and control mapping of interaction devices in virtual environments makes the design of these environments a challenging task. Due to the importance of exploring aspects of the use of such devices, the current study

consisted in exploring the use of three devices in 3D environments: Keyboard-Mouse, Wiimote and Flystick with beginner and advanced users. The type of interaction in the 3D environment depends greatly on the chosen interaction device. From the analysis of the results, we observed that advanced users have very divergent opinion of beginners, which is quite common in 3DUI [8] [6]. In the studied case, the divergence of opinions proved to be stronger when comparing the devices, especially regarding the Flystick, which was the preferred of most beginners and criticized by the advanced participants, who preferred the Keyboard-Mouse. We know that users of 3D games are used to Keyboard-Mouse, which may have made its use seem more natural. With regard to beginners, without previous experience, the more natural may have been one of the devices that were designed specifically for an immersive environment. Should the user experience be decisive in 3DUI? If so, should it be more crucial than in WIMP? If the opinion tends to change with experience, how to design 3DUI? These questions show challenges that still need to be studied further in HCI.

Another finding was about Wiimote, which was the most criticized of all devices. Problems such as ergonomics and imprecise movements were the most cited. The only participant (advanced) who praised this device reported having good experience using it in games. But although he liked this device, he said that some changes should be made to improve it. We also hope to make a small contribution to the design of virtual environments, highlighting their interaction design challenges.

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