A Review on Interaction Techniques in Virtual Environments

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Abstract

With continuous interest and effort over the past few decades, the field of virtual reality has gone through a rapid development. However, improvements in virtual reality technologies and virtual environment interaction have not been matched by corresponding improvement in our knowledge of how to classify the interaction techniques in an established way. Thus, the goal of this paper is to classify the existing interaction techniques in virtual environments and identify the classification factors. First, we gathered previous studies and reviews related to virtual environment interaction. After a thorough examination of the collected works, we were able to identify a variety of virtual environment interaction techniques and their underlying characteristics. According to the characteristics, the existing virtual environment interaction techniques were classified into two main categories, each with three different sub-categories. The categories were characterized to clarify the classification scheme used. Through a systematic review on the virtual environment interaction techniques and their classification methods, this paper would serve as a reference and guidance in understanding the current research trend, and further formulate new research topics related to interaction techniques in virtual environments.

Keywords

Virtual Environment, Virtual Interaction Techniques, Object Manipulation, Human-computer Interaction

1. Introduction

The development of computer technologies and 3D displays has made virtual environments and virtual interfaces accessible to people in all kinds of fields (Göbel, 1996). The term “virtual environment” refers to the environments in which images and interaction abilities are improved through special processing of nonvisual display modalities, such as auditory and haptic, to convince users that they are immersed in a synthetic space (Ellis, 1994). In virtual environments, users can use their eyes, ears, and hands, just as they would normally do in the real world, for performing virtual interactions. Nevertheless, in spite of such rapid diffusion of virtual reality, there seem to have been very few studies that attempted to perform a systematic review and classification of virtual interaction techniques (Gabbard, et al., 1999). Other than Poupyrev, et al. (1999), which systematically categorized the existing virtual interaction techniques by their interaction metaphors, the number of attempts to classify virtual interaction techniques is very scant at this point. The lack of understanding of the existing virtual interaction techniques and their classification methods can impede researchers in developing enhanced virtual reality and virtual interface technologies. Thus, the goals of this study are as follows:

1) Conduct an in-depth review of the existing virtual interaction techniques and their related studies.
2) Identify the existing classification methods of virtual interaction techniques.
3) Develop an up-to-date classification of virtual interaction techniques with a new classification scheme.

2. Related Work

2.1 Virtual Interaction Techniques

The virtual reality technologies started with two-dimensional (2D) input systems, for three-dimensional (3D) input systems were either too expensive, or simply did not exist at all at that time. Such 2D input systems included physical input devices like mice and joysticks, and some studies attempted to integrate simple 3D input methods using light rays or strings into a “simulated” 3D input system. Therefore, at first, the limitation of technology prohibited users’ abilities in virtual environments to simple manipulations, like select, rotate, and move. Some of the examples of such 2D or simulated 3D systems are ray-casting (Roth, 1982), the Bat (Ware, 1990), and SPIDAR (Hirata, et al., 1992). Nonetheless, advances in technologies related to virtual reality, such as head-mounted displays (HMDs) and motion-tracking cameras, have made the application of much more complex virtual interface and interactions possible. Instead of the physical devices acting as pointers or "self" in virtual environment, hand gestures and motions became the standard input methods, thus making the interaction techniques much more immersive to the users. For example, the Go-Go (Poupyrev, et al., 1996), CAVE (Audio Visual Experience Automatic Virtual Environment) (Cruz-Neira, et al., 1992), ISAAC (Immersive Simulation Animation And Construction) (Mine, 1995), and HOMER (Hand-centered Object Manipulation Extending Ray-casting) (Bowman, et al., 1997) are products of virtual interaction techniques with highly advanced 3D inputs. A considerable amount of research has been done on this field, and we categorize the existing virtual interaction techniques according to a novel classification scheme.

2.2 Taxonomies of Virtual Interaction Techniques

A few studies in the past have tried to sort the existing virtual interaction techniques. Hand (1997) examined some of the virtual interaction techniques in many different perspectives, such as type of input devices, feedback methods, viewpoint manipulation, and frames of reference. Bowman, et al. (1997) classified methods for grabbing and manipulating remote objects into two types, "arm-extension" and "ray-casting". This study defined arm-extension as interaction techniques that use virtual arms which can extend as desired by the users, so that the users can manipulate the objects that are far away. The techniques categorized as ray-casting, on the other hand, make use of a virtual light ray that stretches out from the user's hand to grab or manipulate objects out of reach. Poupyrev, et al. (1999) developed taxonomy of the virtual interaction techniques and performed empirical evaluation of the techniques. This study categorized the techniques into "egocentric" and "exocentric", as shown in Figure 1.

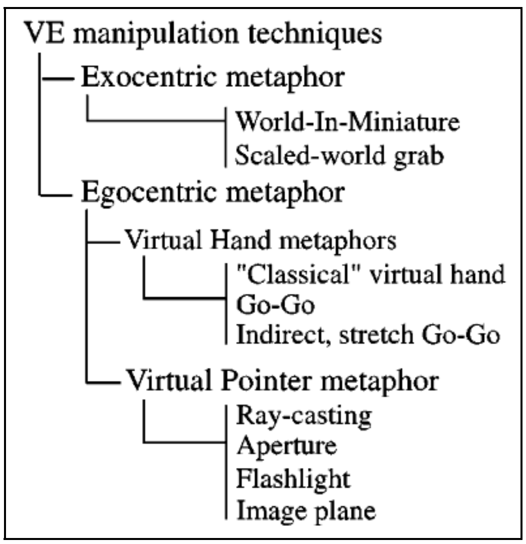

Figure 1: Taxonomy of virtual object manipulation techniques (Poupyrev, et al., 1998)

Unlike the taxonomy of virtual interaction techniques developed by Poupyrev, et al. (1998), which categorized different interaction techniques by their underlying metaphors, Bowman, et al. (1999) tried to understand interaction techniques from their lowest level of tasks, sorting every technique into few basic interaction tasks. The method consists of two steps. First, task analysis is conducted using hierarchic decomposition of certain interaction tasks, placing and partitioning them into different levels of subtasks. Second, each of the lowest subtasks is identified, and components that accomplish them are listed. These basic interaction tasks chosen were selection, manipulation, and release. The taxonomy defined by Bowman, et al. (1999) includes a very broad definition of categorization and so most of the precedent interaction techniques fall into one of these basic tasks. Such taxonomy has many useful applications. They can be verified by fitting known techniques into their categorizing process and by adding different low-leveled subtasks, a new technique may be designed.

3. Proposed Work

3.1 Classification of Virtual Interaction Techniques

In this study, we used a classification scheme derived from the previous egocentric/exocentric method (Poupyrev, et al., 1998; Poupyrev, et al., 1999; Lumsden and Brewster, 2003), as it seems to be the most widely referred scheme as of today.

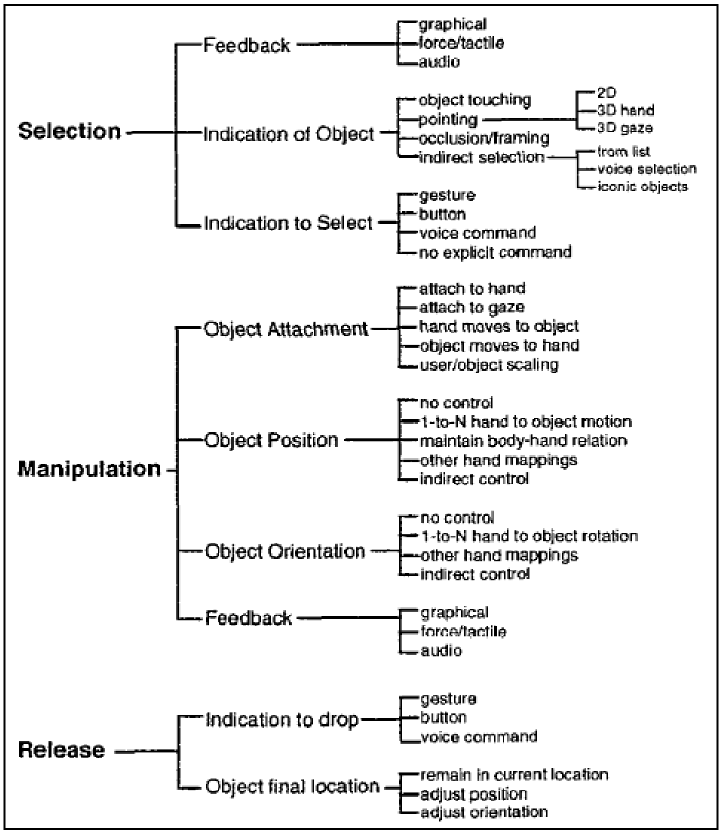

Figure 2: Taxonomy of selection/manipulation techniques (Bowman, et al., 1999)

In addition to that, we added new sub-categories, based on major interaction categories defined by Mine (1995), in order distinguish subtle differences between the virtual interaction techniques. Thus, interaction techniques are classified into 2 main categories, "Egocentric" and "Exocentric", then into 3 sub-categories, "Direct Manipulation", "Physical Control", and "Virtual Control". Table 1 shows the techniques and the related literature classified into these categories. For those techniques without particular names, the names of the devices used are listed instead.

Table 1: Classification of the Virtual Interaction Techniques

Main Category	Sub-category	Techniques or Devices Used	Literature (Author, Year)
Egocentric	*Direct Manipulation*	HMD	(Fisher, et al., 1986)
		Whole-hand Gloves	(Fisher, et al., 1986), (Zimmerman, et al., 1987), (Foley, 1987), (Sturman, et al., 1989), (Venolia, 1993), (Kessler, et al., 1995), (Lee, et al., 2002)
		Pinch Gloves	(Cutler, et al., 1997), (Bowman, et al., 2001)
		Ray-casting	(Roth, et al., 1982), (Jacoby, et al., 1994), (Bowman, et al., 1997), (Poupyrev, et al., 1998)
		Bent pick ray	(Riege, et al., 2006)

		HOMER	(Bowman, et al., 1997), (Pierce et al., 2002)
		Tilt, electric compass, and flex sensors	(Lee, et al., 2005)
		Grab-and-carry	(Cutler, et al., 1997)
		SkeweR	(Duval et al., 2006)
	Physical Control	Mice or joysticks	(Ware, 1990), (Mizell, 2000)
		Aperture	(Forsberg, et al., 1996)
		Interactive stereoscopic computer graphic workspace	(Schmandt, 1983)
		SPIDAR	(Hirata et al., 1992)
	Virtual Control	Go-Go	(Poupyrev, et al., 1996), (Bowman, et al., 1997), (Poupyrev, et al., 1998)
		ISAAC	(Mine, 1995)
		Virtual hand	(Tomozoe, et al., 2004), (Kiyokawa, et al., 2005), (Duval, et al., 2006)
		Voodoo Dolls	(Pierce, et al., 1999), (Pierce, et al., 2002)
		MASSIVE	(Greenhalgh, et al., 1995), (Greenhalgh, et al., 1997), (Benford et al., 1997), (Hindmarsh et al., 2000)
Exocentric	*Direct Manipulation*	Scaled-world grab	(Mine, et al., 1997)
		Scaled-grab	(Simon, et al., 2005)
	Physical Control	World-In-Miniature	(Stoakley, et al., 1995)
		Reconfigurable Tangible Device	(Aguerreche, et al., 2010)
	Virtual Control	CAVE	(Cruz-Neira, et al., 1993), (Mizell, et al., 2000), (Creagh, 2003), (Cabral, et al., 2005)
		GeoWall	(Morin, et al., 2001)
		Virtual control panels	(Su, et al., 1993)
		Responsive Workbench	(Krueger, et al., 1994), (Krueger, et al., 1995), (Cutler, et al., 1997)

3.2 Egocentric Interaction Techniques

According to the dictionary, the word "egocentric" refers to a situation in which a person is preoccupied with his own internal world (Merriam-Webster). As defined from the dictionary, the egocentric interaction techniques allow users to be embedded within the virtual world and perform interactions (Poupyrev, et al., 1998). It is the most common technique used for immersive virtual environment as its manipulation commands are based on human intuitiveness and does not require any pre-training. There are two basic metaphors for egocentric manipulation that have been well defined so far: virtual hand and virtual pointer (Mine, 1995; Poupyrev, et al., 1998; Zhai and Milgram, 1993). With the virtual hand, users are able to perform manipulation commands including hand tracking, gesture recognition, pointing, gazing direction, and hand motions to designate the parameters of interaction tasks. With the virtual pointer metaphor, users manipulate objects by pointing at them. The direction, shape, and methods verifying the selected objects are the parameters of interaction tasks. We classified existing egocentric interaction techniques into three sub-categories based on their characteristics and metaphor scheme.

Direct manipulation: Head mounted display (Fisher, et al., 1986), Whole-hand gloves (Fisher, et al., 1986; Zimmerman, et al., 1987; Foley, 1987; Sturman, et al., 1989; Venolia, 1993; Lee, et al., 2002; Kessler, et al., 1995), and HOMER (Bowman, et al., 1997; Pierce et al., 2002) belong to this category. Such devices and techniques allow users to interact with objects in a virtual world using their intuitive motions.

Physical control: This category includes devices and techniques that use buttons, sliders, dials, joysticks, steering wheels, and other forms of interaction controller that manipulates by a physical control. Mice or joysticks (Ware, 1990; Mizell, 2000), Aperture (Forsberg, et al., 1996), and SPIDAR (Hirata et al., 1992) are some of the major exemplary techniques. The physical control devices have advantage in enhancing users' feeling of presence in the virtual environment, but they often lack the natural mappings that ease an interaction task.

Virtual control: This category includes any forms of an object or thing that can be implemented as a virtual control. Go-Go (Poupyrev, et al., 1998; Poupyrev, et al., 1996; Bowman, et al., 1997), ISAAC (Mine, 1995), virtual hand (Tomozoe, et al., 2004; Kiyokawa, et al., 2005; Duval, et al., 2006), and Voodoo Dolls (Pierce, et al., 1999; Pierce, et al., 2002). Such devices have advantages in the flexibility, but lacks haptic feedback and general difficulties in interaction with a virtual object (Mine, 1995).

3.3 Exocentric Interaction Techniques

The second category of interaction techniques is "exocentric". According to Poupyrev, et al. (1999), exocentric viewpoint is when the user is interacting with virtual environment from the outside, thus utilizing viewpoints not limited to those of the users. In other words, exocentric techniques do not totally immerse the users into the virtual environment, and give a sense that they are not part of the virtual reality while using the technique. Within this category, the three sub-categories are determined as follows.

Direct Manipulation: The techniques that interpret users' gestures or motions directly are defined as direct manipulation. Scaled-world grab (Mine, et al., 1997) and Scaled-grab techniques (Simon, et al., 2005) are some of the main techniques in this category. They both utilize scaling method as a means of making the world more maneuverable. The users can manipulate the world itself or the objects inside virtual environment to adjust the dimensions so that they can perform actions easier.

Physical Control: This category includes exocentric techniques that make use of physically tangible controllers as input devices. World-In-Miniature (Stoakley, et al., 1995) is a fairly well-known method of interaction, with a secondary, scaled-down set of the virtual world present to allow users perform actions through the secondary world. Reconfigurable Tangible Device (Aguerreche, et al., 2010) is found in a recent study where physical devices with different degrees of freedom are used to control the objects inside virtual environment.

Virtual Control: This category includes those techniques with either virtual controllers appearing inside the virtual environment or the controlling devices or methods are hidden from the user. CAVE (Cruz-Neira, et al., 1993) is a very popular virtual environment which uses images projected onto walls to make the user feel like they are inside the virtual world. GeoWall (Morin, et al., 2001) also uses large projection screen to immerse users into the virtual environment. Virtual control panels (Su, et al., 1993) and Responsive Workbench (Krueger, et al., 1994; Krueger, et al., 1995; Cutler, et al., 1997) are also some of the examples of virtually controlled interaction techniques.

4. Conclusion

In this study, we classified the existing virtual interaction techniques using a new taxonomy, combining the categorization schemes of Poupyrev et al. (1998) and Mine (1995). The proposed taxonomy refined the existing egocentric/ exocentric by segmenting each category into three subcategories in order to provide researchers a more clear definition of VEs interaction techniques and a useful reference tool for their researches.

As we can see in Table 1, the techniques are leaning towards direct manipulation and virtual controls in egocentric environment. This is a natural phenomenon as in order for the techniques to maximize their interactivity, sensory vividness, and the overall human performance, high level of immersion is necessary (Biocca, et al., 1995), and egocentric environment satisfies such criteria. Also, egocentric techniques are based on human intuitiveness and do not require much learning in order to use them, which makes them easier and more feasible for people to use. However, exocentric techniques have also been consistently investigated, regardless of their drawbacks in providing the users with a high level of immersion. Exocentric technique such as CAVE, which was introduced in the early 1990s, has drawn massive investments with wide acceptance, expanding its practice to many different research fields. Hence, researchers should consider using egocentric and exocentric interaction techniques adequately depending on their research fields and applications.

Rapid advances in technology have made virtual environments more accessible and affordable than ever. As a result, numerous virtual interaction methods have been proposed, yet not much evaluation has been done regarding their efficiency, accuracy, intuitiveness, learnability, physical or mental stress and many other human factors related issues. Thus, our next goal is how to optimize and enhance the existing virtual interaction techniques to the next level. In order to achieve such a goal, a proper and systematic evaluation method for measuring the performance of interaction techniques is important (Bowman et al., 1999), and our taxonomy can be served as a reference in designing such evaluation methods.

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