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Are Existing Metaphors in Virtual Environments Suitable for Haptic Interaction

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Abstract

Each computer application is designed to allow users to perform one or more tasks. As those tasks can be very diverse in nature and as they can become very complex with a lot of degrees of freedom, metaphors are used to facilitate the execution of those tasks. At present several metaphors exist, all with their strengths and weaknesses.

Our research focuses on haptic interaction and how this can support the user in accomplishing tasks within the virtual environment. This can be realised by integrating force feedback in a fully multimodal communication with e.g. speech and gestures. Therefore, suitable metaphors have to be found. This paper draws an overview of the metaphors currently used in virtual environments, classified by the task they are designed for, and examines if these metaphors support haptic feedback, or how they can be extended to do so.

1 Introduction

Executing a task in a virtual environment, can be seen as a dialog between the user and the environment. This dialog requires certain exchange of information. The user has to communicate his/her intention to the computer, while the computer at its turn has to provide adequate feedback. In order to facilitate the dialog and to improve the intuitiveness of the interaction, metaphors are used. Metaphors explicitly mimic concepts that are already known by the user in another context, in order to transfer this knowledge to the new task in the new context. It is important, however to know that two constraints exist on the usefulness of a metaphor [23]. First of all, a good metaphor must match the task and it must fit the user's previous knowledge in order to be able to establish a transfer of the user's internal model. It has little sense to provide an car driving metaphor if the user doesn't know how to operate a car. Secondly, the metaphor must fit the physical constraints it places on the interface. Indeed, a metaphor makes some actions easy and other actions difficult to do. It is clear that the metaphor must match the particular task to be executed.

It will be clear that, as our every-day interaction with

the physical world is multimodal, metaphors will be often multimodal as well: direct manipulation, gestures, or speech are often used as input modality. Feedback is mostly given via the graphical channel, although audio feedback is frequently adopted as well. Although not heavily used in current metaphors, force feedback is one of the senses users heavily rely on in their daily life, and so this modality provides a great opportunity to the interaction with the (3D) virtual world. Force feedback will open up extra perspectives by preventing the user to make erroneous moves or by giving adequate and direct feedback about the state of the interaction. This paper will look at several metaphors currently known in 3D virtual environments and discusses the availability of force feedback, or how these techniques could be extended.

The next section will explain how tasks in virtual environments can be classified. Based on this classification, the metaphors will be explained in section 2, 4 and 5. We will finish this paper with our conclusions.

2 Tasks in Virtual Environments

A commonly used classification of tasks in virtual environment is stated by Gabbard [11], based on the earlier work of Esposito [9]. In his work, tasks can be classified into three groups:

- Navigation and Locomotion
- Object Selection
- Object Manipulation, modification and querying

All querying and modification of environment variables (menus, widgets, etc.) will be treated as object interactions. This classification has been made for virtual environments, but it can be generalized to all 3D environments, including desktop 3D environments.

In this survey, we will elaborate on each item of this classification. For each group of tasks, we will enumerate the most common metaphors and consider their benefits and drawbacks. We will also discuss their (possible) support for haptic feedback.

3 Metaphors for Navigation Tasks

Navigation metaphors in 2D applications are often restricted to ‘scroll bars’ or the well known ‘hand cursor’ that grabs the canvas to move it around. When navigating in 3D space, 6 degrees of freedom (6DoF) are present. It is clear that we need to overcome several problems in order to provide an intuitive metaphor for 3D navigation. First of all, standard 2D input devices are not always preferable to control all degrees of freedom. It is also known that disorientation of the user will occur more easily when providing more degrees of freedom. The metaphors described in the section below will address these problems. The camera metaphors are described according to the following taxonomy (fig 1). Direct camera control metaphors (d) allows the camera to be directly controlled by the user. With indirect camera control metaphors (i), the camera is controlled activating a single command that moves the camera. Direct Camera control can be split-up in object centric (d-o) and user centric (d-u) metaphors. Object centered metaphors allow the user to easily explore a single object, while user centric metaphors are more suitable for scene exploration. User centric metaphors, at their turn, can be absolute (d-u-a), relative (d-u-r) or both (d-u-a/r). In an absolute user centric technique, a certain position of the input device corresponds to a certain position of the camera, while relative techniques are controlled by indicating in which direction the camera will travel.

In the following paragraphs, we will enumerate the different camera metaphors, each metaphor will be classified within the former taxonomy (see also table 1).

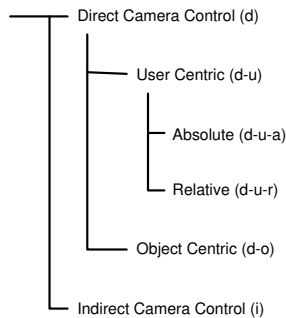


Figure 1: Taxonomy of Camera Metaphors

3.1 Direct Camera Control Metaphors

In this category we find metaphors in which the user directly controls the position and orientation of the viewpoint using an input device. The device can be 2DoF (like a desktop mouse), 3DoF (like a joystick) or 6DoF (like a SpaceMouse or PHANToM device).

3.1.1 User Centric Camera Control

The **flying vehicle** metaphor [23], as well as the haptically controlled crafts [1] represent the virtual camera

as mounted on a virtual vehicle. By means of an input device, the user controls the position of the vehicle by relative movements. This metaphor is by far the most widely used solution when the user has to move around in a limited-sized world. The flying vehicle technique has a lot of variations, from which some of them are described below. The flying vehicle metaphor turns out to be very intuitive. When operating via a 2DoF or 3DoF input device, the other degrees of freedom are accessed via mouse-buttons, modifier keys on the keyboard, or interaction with buttons on the screen. 6DoF devices provide the user with much more possibilities, however, allowing to control all six degrees of freedom can be distracting. Therefore, the movements of the vehicle are often limited to ‘walking’ (3DoF) or ‘flying’ (5DoF), or some rotations can be limited to prevent the user from moving up-side-down. The most important drawback of this metaphor is the amount of time necessary to travel between two distant locations, when navigating in huge environments. Availability of force feedback highly depends on the device: when using 2DoF or 3DoF devices, the feedback is often given by means of vibrations or ‘bumps’ when colliding with an object. In addition, with other devices, such as the SpaceMouse, the passive force feedback of the device can be used to give an idea of the magnitude of the displacement and thus of the vehicles’s speed. Anderson’s craft metaphor implements this feedback with active feedback using a PHANToM device.

Zeleznik [24] describes **UniCam**, a camera manipulation metaphor that relies on 2D gestures with a single-button stylus or a mouse. In contrast to common camera metaphors that are controlled by 2DoF devices, this solution doesn’t require any modifier keys and thus leaving those buttons for other application functionality. One drawback to this solution is the amount of gestures that users have to learn before being able to navigate intuitively. To our knowledge, no work can be found that add force feedback to 2D gestures. However, we can imagine that in some cases haptically constrained gestures by means of a force feedback mouse, can improve the interaction.

From our own work, we know the **camera in hand** [7] and the **extended camera in hand** [5] as two camera metaphors that require a PHANToM haptic device to control the viewpoint. In this solution, the virtual camera is attached to the stylus of the PHANToM device. Consequently, the movements of the stylus are directly and in an absolute manner coupled to the camera position and orientation. Force Feedback enables a virtual plane to induce a more stable navigation. To extend the navigation for exploring larger scenes, the metaphor switches to relative motion by adopting a flying vehicle metaphor when reaching the bounds of the device: a virtual box, limited by the device’s force-feedback capabilities, controls the speed of the camera. The camera in hand metaphor is especially useful in applications where a pen-based haptic device is available, since it doesn’t

Table 1: Overview of Camera Metaphors

	full 6DOF	Application	Other Tasks Possible	Compatible for Haptics	Taxonomy
Flying Vehicle (2-3DOF device)	yes	non-immersive	no	possible	d-u-r
Flying Vehicle (6DOF device)	yes	immersive/non-imm	no	yes	d-u-r
UniCam	no	non-immersive	no	possible	d-u-r
Camera In Hand	yes	non-immersive	no	yes	d-u-a/r
Treadmills	no	immersive/non-imm	no	yes	d-u-r
Gestures	yes	immersive/non-imm	(Sel/Manip)	no	d-u-r
Gaze Directed	no	immersive/non-imm	no	no	d-u-r
Eyeball In Hand	yes	immersive/non-imm	no	no	d-u-a
World in Miniature	yes	immersive/non-imm	Sel/Manip	possible	d-u-a
Speed Coupled Flying	no	non-immersive	no	possible	d-u-r/d-o
Scene In Hand	no	immersive/non-imm	no	possible	d-o
Head Tracked Orb Viewing	no	immersive	no	no	d-o
Teleportation	no	immersive/non-imm	no	no	i
Small Scene Manipulation	no	immersive/non-imm	no	no	i

need an extra device dedicated to navigation. A user experiment has proven the benefits of this technique: especially users with less 3D experience benefit from this metaphor, compared to a flying vehicle metaphor controlled by a 6DoF device (such as the SpaceMouse).

Other navigation metaphors include all kinds of **treadmills** [12]: these solutions mostly use an implementation of the flying vehicle metaphor, in which the vehicle is driven by physical walking movements. It is clear that this is a very intuitive way of moving into the virtual world, although very large and expensive hardware is necessary in order to create a realistic simulation. Also the limited speed of ‘human walking’ can be seen as a common drawback.

Gestures of the human body [22] (similar to UniCam) or **gaze-directed** [4] steering, both ‘relative user centric direct camera control’ metaphors, can be used to ‘drive’ a flying vehicle. Since both techniques don’t use physical hardware that is in contact with the user, no force feedback can be given. Gaze-directed steering seems to be more easily adopted by the user, and it has the advantage that viewing and steering are coupled. However, it requires much head motion and shows up to be less comfortable for the user.

The **eyeball in hand** metaphor provides the user with a 6DoF tracker in the hand. When navigating, the movements of the tracker are directly coupled to the virtual camera in an absolute manner, as if the user is holding his ‘eyeball in his hand’. Since the metaphor relies on the use of a tracker held in the user’s hand, an extension to force feedback is not trivial. One has to be careful when changing to a force feedback enabled device in order not to change the interaction technique itself. Indeed, changing to a mechanical tracking, can fade from the idea of having the ‘eyeball in his hand’. Although this technique provides the user with a maximum of freedom, the metaphor turns out to be very distracting. The limited workspace of the user’s hand also

limits the scope of the navigation which is true for all absolute user centric metaphors (d-u-a).

World in miniature (WIM) [15] is more than just a navigation technique: it must be seen as a more general ‘interaction’ metaphor. From an outside viewpoint (‘God-eye’s view’), a small miniature model of the world is presented. The user can perform his manipulations (including camera manipulations) in the miniature representation. It allows easy and fast large-scale operations. The WIM will be handled in more detail in section 5.2.

Speed coupled flying with orbiting, as described in [21], can be seen as a simplification and extension of the standard flying vehicle metaphors by automatically adjusting some parameters. This solution couples the camera height and tilt to the movement speed. In addition, an orbiting function to inspect certain objects has been integrated. This interaction turns out to be efficient when larger, but relatively straight distances have to be travelled in an ‘open’ scene. When moving in room-like scenes, the advantages will fade. This camera manipulation technique can be classified as a relative user centric direct camera control metaphor. The orbiting function at its turn is an object centric technique. As with the general flying vehicle controlled by 2DoF or 3DoF devices, support force feedback can be possible by use of a force feedback mouse or joystick to give feedback about collisions.

3.1.2 Object Centric Camera Control

The **scene in hand** metaphor [23] provides a mapping between the movement of the central object and the input device. This technique shows its benefits when manipulating an object as it is held into the user’s hand. This solution allows the user to easily ‘orbit’ around the object, but it turns out to be less efficient for global scene

movements. As this is also a relative technique, force feedback (using active feedback or the device's passive feedback) can be used in order to get feedback on the magnitude of the displacement.

Head tracked orbital viewing [13] [14] is more dedicated to immersive 3D worlds. When the user turns his head, those rotations are applied to a movement on the surface of a sphere around the central object. When turning his head to the left, the camera position is moved accordingly to the right. Since head movements are used to control the camera, force feedback is of no importance here. The metaphor is 'object centric', which means that this metaphor only applies to object manipulation, and is not suitable for larger scenes.

3.2 Indirect Camera Control Metaphors

Indirect camera control techniques such as **Teleportation**-metaphors instantly bring the user to a specific place in the 3D world. The teleportation can be activated by either speech-commands, or by choosing the location from a list. However Bowman [2] concludes that teleportation leads to a significant disorientation of the user.

Finally, **small scene manipulation**, as described in our work [6], can be seen as an automatic 'close-up' of the scene. When activated, the computer calculates an appropriate position close to the selected object in order to show the selection within its local context. Next, the camera position is automatically animated to the new position. When disabling the 'small scene manipulation', the original position is restored. This technique allows the user to smoothly 'zoom in' on a particular part of the world and manipulate the object of interest within its local context. In an evaluation study, users sometimes complain about 'getting lost' when the camera automatically moves to the new location, which is even more pronounced with the normal teleportation metaphor. For both the standard teleportation and the small scene manipulation, force feedback will not provide any added value to the interaction.

Table 1 gives an overview of the aforementioned camera control techniques.

4 Metaphors for Object Selection Tasks

In 2D applications, the user can easily access each object in the canvas by direct manipulation. This is not true for 3D environments. Often the third dimension brings along an extra complexity in terms of completing the task in an efficient and comfortable manner. A common difficulty is the limited understanding of the depth of the world, especially when no stereo vision is available. Furthermore, it is not always possible to reach each object in the scene, due to occlusions or the limited range of the input device. Most selection metaphors try to address these common obstacles in

order to make interaction more natural and powerful.

Ray-casting and **cone-casting** [14] are by far the most popular distant selection metaphors. Attached to the user's virtual pointer there is a virtual ray or a small cone. The closest object that intersects with this ray or cone becomes selected. This metaphor allows the user to easily select objects at a distance, just by pointing at them. From our own research, however, we have found that users try to avoid this metaphor as much as possible [6]. The reason why subjects dislike this solution is probably the relative sensitivity of the rotation of the ray. Hence, operating the ray over relatively large distances results in less accuracy. As the metaphor relates to a flashlight in real life, and since flashlights have no force feedback, to our opinion, introducing force feedback will not improve the interaction.

The **aperture based** [10] selection technique provides the user with an 'aperture cursor'. This is a circle of fixed radius, aligned with the image plane. The 'selection volume' is defined as the cone between the user's eye point and the aperture cursor. This metaphor in fact improves the cone-casting by reducing the rotation movements of the ray by simple translations of the aperture cursor. With this metaphor we don't see any direct improvements by adding force feedback, although adding some kind of inertia or constraints upon the movements of the aperture cursor may be useful.

Other **direct manipulation** metaphors such as the 'virtual hand', 'image plane', 'GoGo', ... show their benefits for both selection and manipulation tasks. We will discuss them in detail in the next section (5).

Also **speech** [8] can be used to select objects, provided that the selectable object can be named, either by a proper name or by its properties (location, size, colour, ...). At a first glance, subjects tend to like this interaction technique. However as the 3D world becomes more complex, it becomes more difficult (and also induces a higher mental load) to uniquely name and remember each object. Ultimately, it is also true that speech recognition is still far away from a fail-safe interaction technique, which often leads to frustration. When a selection command has been succeeded or failed, feedback can only be given to the user via the visual or the auditory channel.

Table 2 gives a short overview of the different selection metaphors.

5 Metaphors for Object Manipulation Tasks

Most object manipulation techniques can also be used for object selection tasks. Therefore, the explanation below also can be applied on the previous section (4).

According to Poupyrev [19], object manipulation tasks can be divided into two classes. With the exocentric techniques, the user is acting from outside the world,

Table 2: Overview of Selection Metaphors

	Distant action possible	Direct Manipulation	Other Tasks Possible	Compatible for Haptics
Ray/Cone casting	yes	yes	yes	no
Aperture based	yes	yes	no	no
Virtual Hand	no	yes	yes	yes
Image Plane	yes	yes	yes	no
Gogo	yes	yes	yes	yes
Speech	yes	no	yes	no

from a ‘god-eye’s-view’. This is in contrast to the egocentric techniques where the user is acting from within the world. In turn, egocentric metaphors can be divided in ‘virtual hand’ and ‘virtual pointer’ metaphors. (see fig 2)

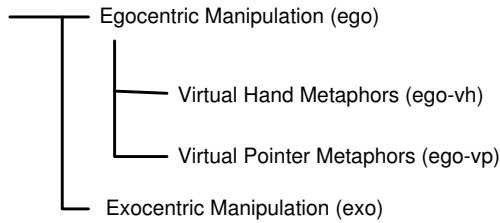


Figure 2: Taxonomy of Object Manipulation Metaphors

5.1 Egocentric manipulation metaphors

Egocentric manipulation metaphors interact with the world from a first person viewpoint. In contrast to exocentric metaphors, these solutions are generally less suitable to large-scale manipulation, but they will show their benefits in relatively small-scale tasks such as object deformation, texture change, (haptic) object exploration, menu or dialog interaction and object moving and rotating.

The **virtual hand** metaphor is the most common ‘direct manipulation’ technique for selecting and manipulating objects. A virtual representation of the user’s hand or input device is shown in the 3D scene. When the virtual representation intersects with an object, the object becomes selected. Once selected, the movements of the virtual hand are directly applied to the object in order to move, rotate or deform it. When the coupling between the physical world (hand or device) and the virtual representation works well, this interaction technique turns out to be very intuitive, since it is similar to every-day manipulation of objects. In addition, a lot of work has already been done to improve the interaction with force feedback. Force feedback can return information about a physical contact, mass, surface roughness and deformation. The main drawback of the virtual hand metaphor, is the limited workspace of the user’s limbs or the input device, which makes distant objects

unreachable. This problem will be addressed in the subsequent solutions.

The **GoGo** technique [20] addresses the problem of the limited workspace by an interactively non-linear growing of the user’s arm. This enlarges the user’s action radius, while still acting from an egocentric point-of-view. Several variations on the GoGo concept exist [3]. Stretch GoGo divides the space around the user in three concentric regions. When the hand is brought into the innermost or the outermost region, the arm grows or shrinks at a constant speed. Indirect stretch GoGo uses two buttons to activate the linear growing or shrinking. Force Feedback can be enabled for the basic GoGo technique as like a virtual hand metaphor. For the stretch GoGo or the indirect GoGo, the force feedback can even have a more pronounced role in order to produce feedback when linear growing is activated.

HOMER, which stands for Hand-centered Object Manipulation Extending Ray-casting [3], and **AAAD** (Action-at-a-Distance) [14] both pick the object with a light ray (as with ray-casting). When the object becomes attached to the ray, the virtual hand moves to the object position. These techniques allow the user to manipulate distant objects with more accuracy and less physical effort. For the drawbacks, we can refer to the same problems we have encountered when using ray-casting (see section 4).

We developed the **Object in Hand** metaphor [6] in order to allow the user’s non-dominant hand to grab a selected object or to bring a menu into a comfortable position. By bringing the non-dominant hand close to the dominant hand, a proprioceptive frame of reference is created: the non dominant hand virtually holds the object (or menu) in respect to the dominant hand. Now the user can interact with the object having a (haptically enabled) virtual hand metaphor. When releasing the object, it automatically moves back to its original position. The main benefit of this approach is its intuitiveness: in our every-day life, we always bring objects into position with our non-dominant hand in order to manipulate them with the other hand. A current technical drawback for desktop environments is the way we have to track the non-dominant hand, which often encumbers the user with cables and a tracker, but we believe better solutions will be available in the near future.

Ray-casting by itself is less suitable for object manipulation: once the object is attached to the ray, the user

Table 3: Overview of Object Manipulation Metaphors

	full 6DOF	Distant action possible	Other Tasks Possible	Compatible for Haptics	Taxonomy
World In Miniature	yes	yes	selection	possible	exo
Scaled World Grab	yes	yes	selection	yes	exo
Voodoo Dolls	yes	yes	camera	possible?	exo
Virtual Hand	yes	no	selection	yes	ego-vh
GoGo	yes	yes	selection	yes	ego-vh
Homer/AAAD	yes	yes	selection	yes	ego-vh
Object In Hand	yes	yes	no	yes	ego-vh
Ray-Casting	no	yes	selection	possible (6dof req.)	ego-vp
Image Plane	no	yes	selection	no	ego-vp

only has three degrees of freedom left, while the object is still moving on the surface of a sphere. Since this interaction technique heavily relies on rotations with the input device, force feedback can only make sense when using a 6DOF haptic device. In that case we can see any benefits for simple object movements.

Image Plane interaction techniques [17] interact on the 2D screen projections of 3D objects. This technique is suitable for both immersive and non-immersive applications. The user can select, move or manipulate objects by pointing at them with a regular 2D mouse or by ‘crushing’ or pointing at the object with the finger. Since the ‘image plane’ technique is a 2D interaction for a 3D world, manipulating objects will not be possible with 6 degrees of freedom. Haptic feedback will not provide much added value.

5.2 Exocentric manipulation metaphors

Exocentric manipulation metaphors will execute the manipulation task from an outside viewpoint. Therefore those interaction techniques are especially usable in situations where the task is spread over relatively large distances within the scene, such as moving objects. Object manipulation tasks that require very precise interaction, such as object deformation, will be more difficult with this kind of metaphors.

The **world in miniature** (WIM) [15] metaphor, as described in 3.1.1, presents the user a miniature outside view of the world. This miniature can not only be used for navigation, but also for selecting or manipulating objects. This technique is especially useful when manipulations over large distances are required, but lacks accuracy due to the small scale of the miniature representation. Another drawback is the screen-space that is occupied by the WIM, although this can be solved by toggling the representation on and off. To our opinion, force feedback can improve the interaction in the same way as it can be used for the virtual hand metaphors. It provides the user with a direct and intuitive feeling in the miniature world.

With the **scaled-world grab** [16] technique, the user can bring remote objects closer by: based on the user’s

arm extension, the distance to the object will be changed correspondingly. Once the world has been scaled, the interaction is similar to a virtual pointer or virtual hand interaction. According to the author, this metaphor turns out to be very intuitive: ‘In our informal user trials we have observed that users are often surprised to learn that scaling has taken place, and that they have no problem using the technique.’

The **voodoo dolls** [18] metaphor is a two-handed interaction technique for immersive virtual environments. With this technique, the user dynamically creates ‘dolls’: transient, hand held copies of the objects they represent. When the user holds a ‘doll’ in his right hand, and moves it relative to a doll in his other hand, the object represented by the right-hand doll will move relative to the object represented by the left-hand doll. This technique allows manipulation of distant objects and working at multiple scales. It takes advantage of the user’s proprioceptive frame of reference between his dominant and non-dominant hand. New dolls are created using the (egocentric) image plane technique (see 5.1). As the original Voodoo Dolls metaphor is designed to be used with two gloves, it is not easy to introduce haptic feedback without essentially changing the metaphor. Air filled or vibrating Haptic gloves or even exoskeletons (such as the CyberGrasp), can be used in order to create a feeling of ‘grasping’ the virtual doll.

Table 3 gives an overview of the existing manipulation techniques.

6 Conclusion

As most interaction techniques in 3D environments rely on metaphors, this paper has drawn an overview of the most common interaction metaphors currently known and looks into their (possible) support for haptic feedback. For some metaphors (such as gestures, speech or some immersive interaction techniques) little added value can be achieved by using force feedback or even those metaphors are unable to support force feedback. Other metaphors or variations already have build-in support for force feedback (such as camera in hand, virtual pointer, ...) or they can be easily extended. We believe

this paper has given a good starting point for designers of multimodal applications, who want to add force feedback to the metaphors in order to better support the tasks in their application.

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