CyberPsychology & Behavior
Volume 5, Number 5, 2002

A User Interface Model for Navigation in Virtual Environments

MÁRCIO SEROLLI PINHO, M.Sc., B.SC., LEANDRO LUÍS DIAS, B.Sc.,
CARLOS G. ANTUNES MOREIRA, B.Sc.,
EMMANUEL GONZÁLEZ KHODJAOGHLANIAN, B.Sc.,
GUSTAVO PIZZINI BECKER, M.Sc.,and LÚCIO MAURO DUARTE, M.Sc.

ABSTRACT

One of the most complicated tasks when working with three-dimensional virtual worlds is the navigation process. Usually, this process requires the use of buttons and key-sequences and the development of interaction metaphors that frequently make the interaction process artificial and inefficient. In these environments, very simple tasks, such as looking upward and downward, can became extremely complicated. To overcome these obstacles, this work presents an interaction model for three-dimensional virtual worlds, based on the interpretation of the natural gestures of a real user while he/she is walking in a real world. This model is an example of a non-WIMP (Window, Icon, Menu, Pointer) interface. To test this model, we created a device named "virtual bike." With this device, the user can navigate through the virtual environment exactly as if he were riding a real bike.

INTRODUCTION

With the coming of real-time graphic libraries such as Direct3D and OpenGL, the exhibition of three-dimensional synthetic environments that are visually very similar to real ones has become possible.

When the interaction needs in these virtual environments are small and the main tasks are restricted to the exhibition of objects and their manipulation with rotation and translation operations, the problem seems to be resolved. When the interaction tasks are limited to navigation along predefined paths, there is still not a problem.

However, when it is necessary to do fast and natural navigation in an environment similar to the real world, some problems appear with the user interface tools available currently. In general, this navigation process involves the use of buttons and keys and the creation of interaction metaphors that make the process not very natural and of reduced efficiency.

In these environments, simple movements (to lower or to elevate the head, to walk to the side or forward) become very complicated and a little unnatural. Examples of these are the very well-known navigators Nestcape, Virtus, Internet Explorer, and Worldtoolkit. This happens mainly because we are using the traditional WIMP (Window, Icon, Menu, Pointer) interface paradigm, in essentially three-dimensional applications, where the user's body is an important part of the interaction process.

With the advent of virtual reality, the interaction formed between human and machine had a great evolution in terms of quality. This increase in the interface quality has its expla-

Faculty of Informatics, Pontifical Catholic University, Rio Grande do Sul, Brazil.

nation in the fact that virtual reality provided more intuitive ways for the users to interact with the systems, without the need of control buttons or other resources.[2,16,14]

In this work, we create an interface model that tries to accomplish the human–computer interaction in a more direct way. The central idea is to map each user's gestures directly to movements inside the virtual world, without requiring memorization of metaphors and sequences of buttons to interact in the environment.

Virtual environments

A virtual environment can be seen as dynamic three-dimensional scenery, modeled through computer graphic techniques and used to represent the visual part of a virtual reality system. The virtual environment is nothing other than scenery where the users of a virtual reality system can interact.

An important feature of a virtual environment is that it be a dynamic system. In other words, the scenerios are modified in real time as the users interact with them. A virtual environment can be projected to simulate an imaginary environment as close to the real one as possible.

Also denominated "virtual worlds," environments can be modeled through special tools, the most popular of which is VRML.[6,11] The degree of interaction in a virtual environment will depend on the adopted interface, besides the devices associated with the system.

User interfaces in virtual environments

Virtual reality brings a new user interface paradigm. In this paradigm, the user is not only in front of the monitor, but he or she fall inside the interface. With special devices, virtual reality tries to capture the user's movements (in general, arms, hands, and head) and, starting from these data, it tries to accomplish the human–machine interaction. The interface in a virtual reality system tries to be similar to reality, trying to generate the sense of presence[3,9,20,21] in a three-dimensional synthetic environment through a computer-generated illusion. This sensation, called "immersion,"[7] is the most important characteristic in virtual reality. The quality of this immersion or the degree of illusion (or how real this illusion seems to be) depends on the interactivity and on the degree of realism that the system is capable of providing.

Interactivity[10] is given the capacity that the system has to give answers to the user's actions. If the system answers in an instantaneous way, it will generate in the user the feeling that the interface is *alive*, creating a strong sensation of reality. For this reason, virtual reality is a computer system that should use real-time techniques for user interaction. The degree of realism, is given by the *quality* of these answers. The more similar to a real scene it is (presenting an image or emitting a sound), the more involved the user will be.

Non-WIMP interfaces

The *non-WIMP interfaces* are characterized by involving the user in a continuous and parallel interaction with the computational environment. They are user interfaces that do not depend on interface objects to be accomplished.[15,22] The main idea is to have interfaces that involve the user in a complete way, interpreting all his or her gestures (head, body, eyes, arms gestures) through special devices. This interpretation should be continuous and parallel, and the generation of sensations on the user should reach all of his or her senses, including those usually used (vision and audition), but still adding the possibility of generating sensations such as touch and strength, as well as others such as cold and heat.

Today, the most developed form of the *non-WIMP* interface is a three-dimensional virtual reality environment. In these environments, we employ a constant updating of the images presented to the user. Besides this, an answer can be generated in response to any movement.

THE PROPOSED INTERFACE MODEL

A model without navigation metaphors

Analyzing the problems presented in the previous section, we created an interface model that tries to accomplish the human–computer interaction in a more direct way. The central idea is to map each user's gestures directly to movements inside the virtual world, without requiring memorization of metaphors and sequences of buttons or keys to interact in the environment.

As other studies have already shown, a very generic interface tends to become difficult to use in specific complex applications.[5,19] For this reason, we decided to define a model to treat the specific problem of navigation. We did not worry, in the model, about the problem of object manipulation.

The available movements

By observing a cyclist's movements while he or she rides through a city, we have identified a group of movements that are usually executed to analyze a specific place:

- To look to the sides, upward, down, or back
- To move the head closer to an object to see it in more detail
- To walk forward
- To stop movement
- To change the direction of movement
- To increase and to reduce the speed of movement

In our experiments, a cyclist was taken as our base; however, we could have opted for other movement forms such as walking or driving a car. We chose the cyclist for two reasons: in the case of walking, the movements are slow; in the case of driving a car, the possibility of the detail analysis (interaction with the environment) is reduced.

User interface actions

Starting from the identification of the user movements in the real world, which we named goals, we defined a set of movements the user should accomplish on the interface, in order to execute his or her tasks. Based on this, the relationships shown in Table 1 were defined.

EVALUATING THE USER INTERFACE MODEL

In order to test the proposed model, a navigation device was built based on the interpretation of a bicycle's movements and on the exhibition of images using a virtual reality head-mounted display (HMD). We adapted a set of sensors on a bicycle, and by reading these sensors, we accomplished the movement.

After building the prototype device, we developed a group of tests in order to evaluate in practice, if this device makes the navigation easier or not, and if the model can be considered valid for the target application.

In the following sections, we present details about the prototype construction and about the tests accomplished.

Virtual bicycle: The test-tool for the user interface model

The built prototype is a real bicycle that was hung up on a tripod allowing one to pedal it without moving. To capture the movements of the handlebar we attached a potentiometer on it. A dynamo coupled to the wheel reads the speed of the movement. A position tracker captures the movement of the user's head.

TABLE 1. THE USER'S GOAL VERSUS USER MOVEMENTS

Goal	*User movement on the interface*
To look to the sides, upward, down, or back	To move the head
To move the head closer to an object to see it in more detail	To move the head
To walk forward	To pedal
To stop the displacement	To stop
To change the direction of movement	To rotate the handlebar
To increase and to reduce the speed of movement	To pedal faster or more slowly

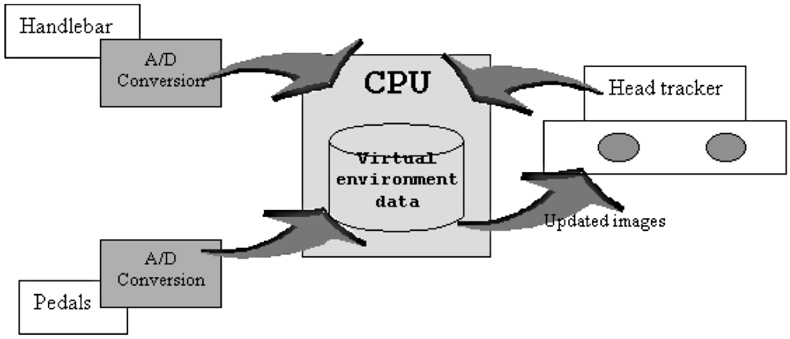

FIG. 1. The prototype architecture.

The developed architecture can be seen in the Figure 1.

Reading the bicycle and user's movements

To read the data from the bicycle, two sensors were used. One of them attached to the handlebar (a potentiometer) and the other attached to the bicycle's wheel (a dynamo; Fig. 2).

The analog/digital signal conversion was done through an equipment called TNG-3 Interface.[13] The connection of the TNG-3 and the computer is made via serial port.

To accomplish the user's head movement interpretation, we used an ISOTRACK II position tracker, from Polhemus.[18]

Scene rendering

The displayed three-dimensional images try to simulate a city where the user can navigate. For the exhibition of these three-dimensional scenes, the OpenGL[23] graphics library and the virtual reality HMD called I-Glasses[12] were used.

The cities used were modeled with an editor specifically created for this task. In Figure 3, a user's view can be observed. It is important to notice that there are no controls or menus on the interface, just the three-dimensional images.

Modeling the cities

In order to allow the navigation and the execution of detailed tests, we decided to model our own validation sceneries. For this task, we created the *City Editor*.[4] This tool allows the fast creation of small cities. They are cities with streets, buildings and trees. These entities were considered detailed enough to give to the user the visual sensation of a city. The Editor is able to save cities in VRML and DXF file formats. Figure 4 shows the Editor's screen and the visualization of a city in a VRML navigator.

The methodology of the validation tests

The evaluation of the proposed user interface model was done comparing the results of the use of the model and use of a commercial

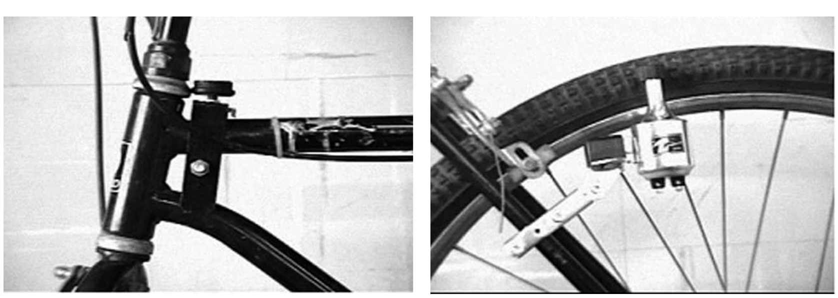

FIG. 2. Movement sensors attached to the bicycle.

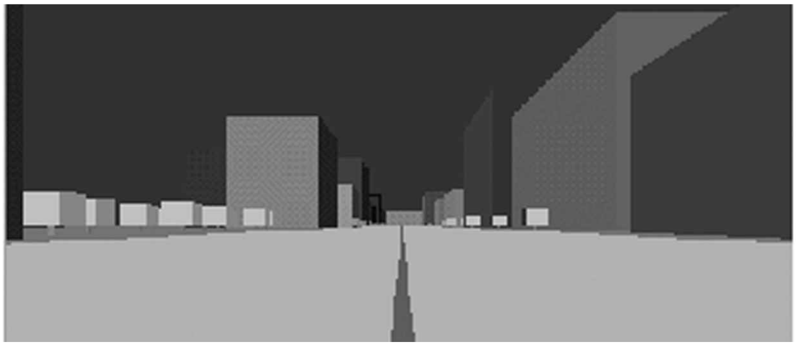

FIG. 3. Example of the user's view.

navigator, like Internet Explorer. In Figure 5, a user during a test can be observed.

In order to test the proposed model and the built device, some tasks that the user must execute were defined.[1] These tasks were the following:

- To walk on a defined path
- To look for a defined object
- To recognize the objects of the environment after a navigation
- To return to a certain point of the city
- To analyze details in a specific part of the city

Starting from these tasks, some parameters were defined in order to evaluate if the model is useful (or not) to accomplish the tasks. The tasks and their parameters can be seen Table 2.

To apply the tests, a group of two cities were chosen, and the following tasks were defined:

a. Go straight ahead, turn right on the third street and turn left after the green building.
b. On the third street on the right there is a white box behind a building. Try to find it.
c. Walk on the two streets on the right side of this avenue. (When the user returns we asked him: Do you remember how many trees you have seen?).
d. Try to find the white box of the task b again. Read what is written in the plate in front of that red building.

These tasks were performed by the 16 users in the following way: half of them used Internet Explorer first, and the other half used the Virtual Bicycle first. This was done in order to

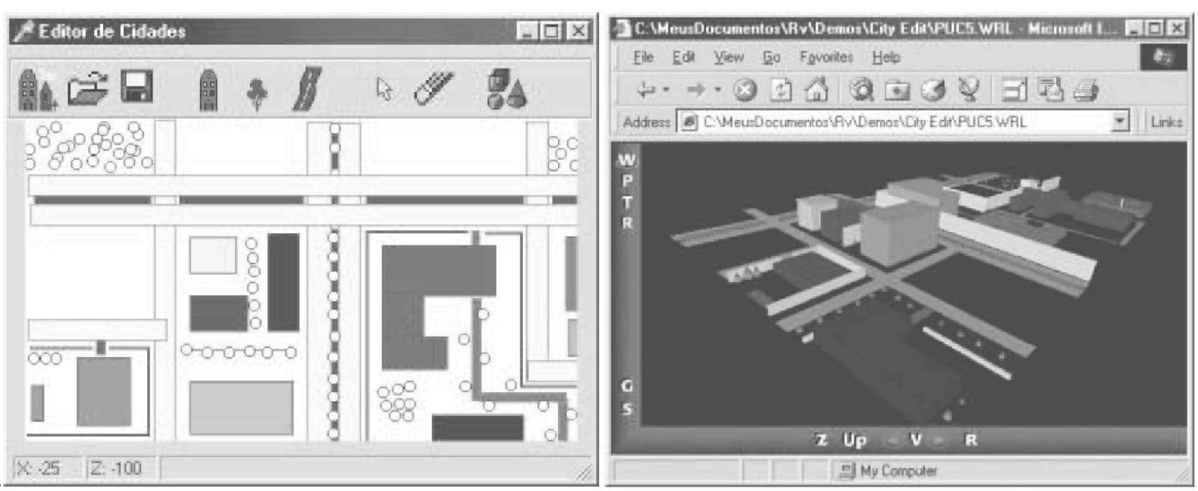

FIG. 4. The city editor.

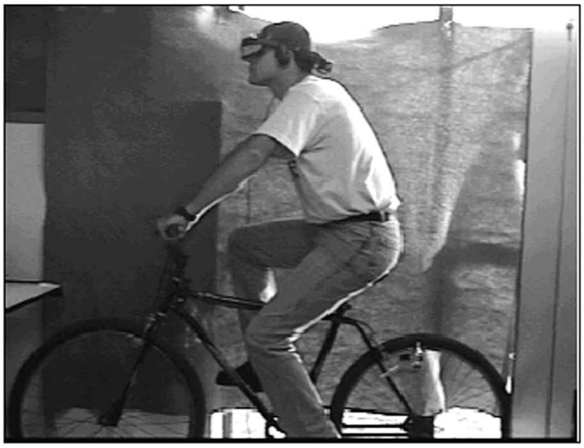

FIG. 5. User in the virtual bicycle.

evaluate if the previous knowledge of the scenery could affect the user's performance.

The results of the validation tests

The results obtained in the development of each task are expressed in Tables 3–7. The order in which the interfaces were used did not alter the results of the tests.

CONCLUSION

In a general way, the obtained results were quite positive for the proposed model. In most of the cases, the developed tool was very superior to the existent commercial navigators. Even for expert users on a three-dimensional navigator (seven of 16), the use of the proposed tool was considered very efficient. Some users noticed that they felt tired and uncomfortable in having to pedal. Some users found the HMD image quality unsatisfactory. The used resolution is limited to 640 × 480 by the equipment.

The best results obtained with the user interface model were in the test of "To analyze details in a specific part of the city." This is due mainly to the fact that, with the built tool, the user just needs to move the head to look closer to an object, without the need to use key combinations or other artifices. It was also noticed that user movements were much softer with the use of the proposed model. We are now beginning to undertake studies to treat the prob-

TABLE 2. TASKS AND THEIR RESPECTIVE PARAMETERS

Tasks	*Parameters*
To walk on a defined path	Total time spent Level of difficulty
To look for a defined object	Total time spent
To recognize the objects of the environment after a navigation	Number of recognized objects
To return to a certain point of the city	Total time spent
To analyze details in a specific part of the city	Level of difficulty

TABLE 3. TASK A: TO WALK ON A DEFINED PATH

Parameter	*Bicycle*	*Navigator*
Total time spent (on average)	25 sec	40 sec
Level of difficulty		
Easy	25.00%	18.75%
Medium	62.50%	43.75%
Difficult	12.50%	37.50%

TABLE 4. TASK B: TO FIND A DEFINED OBJECT

Parameter	*Bicycle*	*Navigator*
Total time spent (on average)	28 sec	35 sec

TABLE 5. TASK C: TO RECOGNIZE THE OBJECTS OF THE ENVIRONMENT AFTER A NAVIGATION

Parameter	*Bicycle*	*Navigator*
Percentage of successes	75%	50%

TABLE 6. TASK D: TO RETURN TO A CERTAIN POINT OF THE CITY

Parameter	*Bicycle*	*Navigator*
Total time spent (on average)	20	35
Gain in relation to first time	20.00%	12.50%

TABLE 7. TASK E: TO ANALYZE DETAILS IN A SPECIFIC PART OF THE CITY

Parameter	*Bicycle*	*Navigator*
Level of difficulty		
Easy	68.75%	37.50%
Medium	18.75%	31.25%
Difficult	12.50%	31.25%

lem of direct manipulation of three-dimensional objects using virtual reality techniques.

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Address reprint requests to:
Márcio Serolli Pinho, M.Sc.
Faculdade de Informática—PUCRS
Av. Ipiranga, 6681
Porto Alegre, RS, Brazil

E-mail: pinho@inf.pucrs.br