v-Glove

A 3D virtual touch interface

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Abstract— **Traditional interaction devices such as mouse and keyboard do not adapt very well to immersive environments, since they were not ergonomically designed for it. The user may be standing or in movement and these devices were projected to work on desks. Moreover, in the current interaction model for immersive environments, which is based on wands and 3D mice, a change of context is necessary every time to execute a non-immersive task. These constant context changes from immersive to 2D desktops introduce a rupture in the user interaction with the application. The objective of this work is to develop a device that maps a touch interface in a virtual reality immersive environment. In order to interact in 3D virtual reality immersive environments a wireless glove (v-Glove) was created, which has two main functionalities: tracking the position of the user's index finger and vibrate the fingertip when it reaches an area mapped in the interaction space to simulate a touch feeling. Quantitative and qualitative analysis were performed with users to evaluate the v-Glove, comparing it with a gyroscopic 3D mouse.**

Keywords— wireless glove; immersive environments; optical-tracking; haptic; tactile feedback

I. INTRODUCTION

Recently, interfaces based on single or multi-touch gestures have become quite common in everyday use. This is mainly due the fact modern mobile devices have these resources integrated. Smartphones and tablets are considered quite simple and useful for gesture interactions, thus have a significant role in the spread of this new computer interface way of use.

Based on this successful experience, it is suposed that this kind of interaction can also be applied to immersive virtual reality environments. In recent years, several research initiatives in the field of virtual reality (VR) have focused on the development of interaction techniques for selection and manipulation of objects, navigation and wayfinding [1][2][3]. Techniques for controlling application parameters were also studied, allowing the change of scalar values and the choice among alternative menu options. However, interfaces for system control in virtual environments have not been studied in more deeph [4].

Since interface controls are an important part of conventional desktop interfaces, adapting these controls for virtual environments is mandatory. A limited number of control widgets, like butons, can be easily accessed, but does not adequately meet the more complex situations such as selection, menu navigation, and alphanumeric input. Thus, all solutions that enables 2D menus adapted to immersive environments face problems as it is necessary to reach a menu item in the interaction space [5].

Some devices were created and enhanced specifically for immersive environments, such as wands, gloves and 3D mice, providing a more appropriate interface to the user of this kind of environment. However, these devices have a high cost, need an often-complex infrastructure (cables, cameras and sensors) and have limitations when faced with situations common in WIMP (Windows, Icons, Menus and Pointers) paradigms.

Thus, the user is forced to make several changes of context every time it is necessary to accomplish a task which is not supported in immersive mode. These constant changes in the context of immersion introduces a break in the way of user interacts with the application. Furthermore, these changes often force the users to disassemble the immersion apparatus like the HMD (Head Mounted Display) and gloves, forcing them to sit at a table to perform the interaction tasks necessary and having to return to the immersive way. This avoids the use of such application for longer periods of time or demands the support of a second person to execute WIMP related tasks.

The aim of this paper is to explore the possibilities of using a touch-like interface in an immersive virtual reality environment. The approach chosen was to use a virtual touch screen mapped in the 3D space. We intend to investigate the advantages and disadvantages of this approach.

A glove was built for interaction in immersive environments. This glove was designed through the use of electronic components together with a 3 DOF (degress of freedom) IR (infra-red) optical tracking system. The cameras used were those integrated on the Wii Remote control, also known as WiiMote. Actuators were used to create the vibration sensation and radio transmitters for the communication between the glove and the computer. Based on these features it is intended to simulate the feeling of touching in a virtual immersive environment.

The operating principle of the v-Glove is based on tracking the position of the index finger and mapping it to X and Y display coordinates, similar to a traditional desktop mouse. By moving the finger to the right side, for example, the mouse pointer moves on the screen following this same direction. The operation of clicking and dragging objects on the surface works based on the Z reference axis. When bringing the fingertip to a predetermined point in Z, the system detects the intent to click on the object pointed at that moment. To reproduce the movement of dragging, the user just have to keep the fingertip in the touch area while moving his hand in X and Y axis.

A proof of concept was conducted with the tasks of navigation in CAD models, selection of objects and interaction with the menus adapted for the software.

Qualitative and quantitative analysis were conducted with users divided into groups according to a profile of exepeience in the use of 3D applications. All tests were video recorded and the interviews were audio recorded for a more detailed analysis.

The remainder of this paper is organized as follows. Chapter 2 describes some related works that serve as reference and inspiration for this research. The technolgy used is described in the chapter 3. The proposed solution is presented in detail in chapter 4. Chapter 5 presents a case study of the proposed solution with the results presented in chapter 6. Chapter 7 presents the conclusions and some future work proposals.

II. RELATED WORK

Similar relevant projects, each one with different ideas, are presented in the following.

A. *Tactile feedback in immersive VR applications*

The system proposed by Scheibe, Moehringer and Froehlich [6] is a tactile feedback system made for the fingertips in an immersive virtual reality application. The system consists of wired thimbles involving the tips of each finger (Figure 1). In order to simulate the contact with a surface, the length of the wire is shortened to make them to come into direct contact with the fingertips and a vibration is caused in the wire to enhance the user's perception of a tactile stimulus. Both the shortening and relaxation of the wires as the process of vibration is controlled by a micro-controller that receives commands from a virtual reality application. Studies have shown that the tactile feedback improved the easiness and reliability of direct manipulation tasks. Bullion and Gurocak also presented a compact force feedback glove in [7]. Their main objective was to reduce the size and the number of actuators in a haptic glove, increasing user hability to interact with virtual environments.

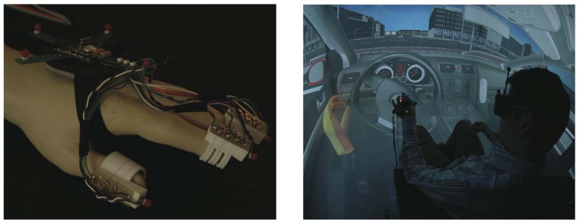


Figure 1 . Tactile Feedback at the Finger Tips [6].

Our propose has the advantage of the absence of wires between the glove and the tracking system, which improves user mobility, especially considering the context of highly immersive environments.

B. *A.R.T Finger Tracking System*

A.R.T. makes tracking systems for immersive virtual reality environments and has a specific device for finger tracking [8] (Figure 2). This glove allows the tracking of user hand orientation and position of up to five fingers at the same time. The communication between the glove and the control center is wireless. A pair of infrared LEDs are used on each finger for tracking. Each of these sets of LEDs emits light at a specific timming, thus allowing the cameras to identify the fingers individually. This sollution has no tactile feedback integrated.

Figure 2 . A.R.T. Finger Tracking System with 3 and 5 Fingers [8].

C. *Virtual Touch Screen*

Tosas and Li [9] had proposed a mixed reality environment that allows users to interact with a virtual touch screen. Techniques of computer vision are used to detect the hand and gestures of typing on a virtual keypad. The idea is that you can interact with elements on a graphical user interface with clicks made with your bare hands on windows, icons and menus similar to windows managers traditionaly used in desktop environments. The proposed system consists of an HMD that allows the user to visualize the virtual keyboard, a camera to capture the hand movements and the software to identify and track hand position, which also generates an audible and visual response when keys are pressed. The click detection is done by identifying the shortening of a finger in the image, when the finger was bent (Figure 3).

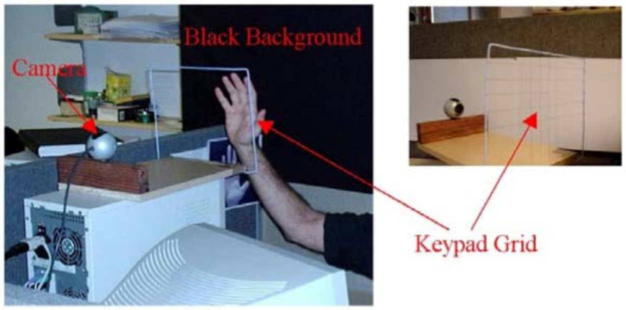


Figure 3 . Virtual touch screen [9].

D. *Augmented Reality 3D keyboard*

Lee and Woo [10] have proposed a wearable augmented reality 3D keyboard, called ARKB (3D Augmented Reality Keyboard), which allows a user to enter text or control widgets without the use of conventional keyboard and mouse. The ARKB makes use of depth information obtained from a stereoscopic camera attached to an HMD, with three modules: (i) 3D tracking of hands, (ii) natural interaction with the fingers and (iii) audiovisual feedback. It works through the recognition of fiducial markers captured by the stereoscopic camera and the calculation of the 3D position and orientation of the markers. The system then displays the image of the virtual keyboard in front of the user, while the ARKB detects the fingertips. An audiovisual feedback occurs whenever a click is detected to increase the realism of the user experience.

III. TECHNOLOGY

A. *Arduino Micro-controller*

The Lilypad Arduino micro-controller is a version of the well-established processor Arduino developed by SparkFun Electronics to be used in clothes [11]. The programmable microprocessor model Arduino Lilypad Main Board 328 is presented in Figure 4(a).

The XBee modem is a component supplied by Digi International Inc. and can be coupled to a Lilypad XBee shield for use in wearable circuitry [12]. XBee implements the ZigBee protocol for wireless communication and has a 1mW microchip antenna with a range up to 100 meters and data transmission rate of 250 kbps (Figure 4(b)).

The Lilypad Vibe Board component is an actuator capable of vibrate when powered by 5 volts. It is also built into a wearable configuration as shown in Figure 4(c).

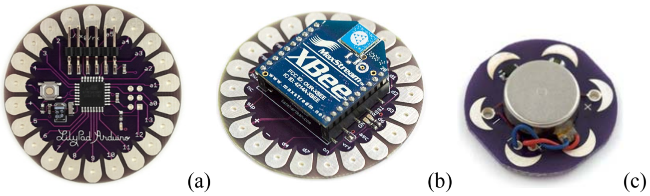

(a) (b) (c)

Figure 4 . (a) Lilypad Arduino, (b) XBee and (c) Vibe Board [11].

B. *WiiMote*

The camera chosen for the tracking system is the one integrated to the remote control of the Wii video game, known as WiiMote. This camera has a built in filter to capture only the infrared range, with greater sensitivity to wavelengths near 940nm. The Wii Remote uses bluetooth technology for wireless communication.

IV. SOLUTION

The purpose of this research is to study the advantages of applying similar concepts of the touch and multi-touch interfaces on immersive virtual reality applications. The main focus was the development of a glove to interact with a virtual touch screen in an immersive projection environment. The hardware view of the solution developed is shown in Figure 5. All elements built were designed for its use in environments without the availability of tables for keyboard and mouse, beside other ergonomic features of immersive environments, like the need for user mobility and low luminosity.

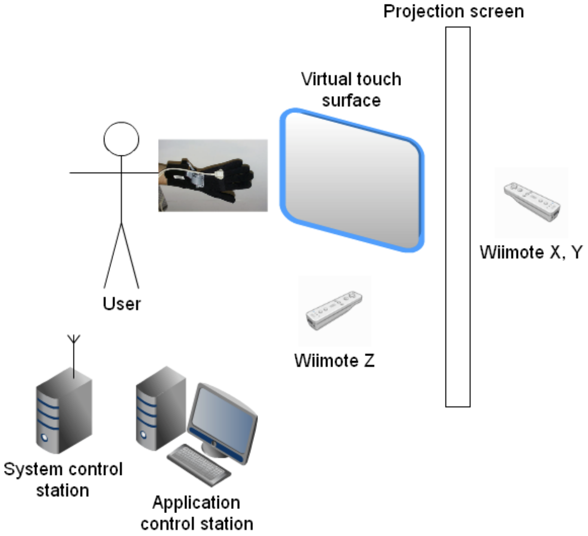


Figure 5 . Schema of the v-Glove hardware.

A. *v-Glove (Tactile Feedback)*

Different approaches can be considered when designing a glove for interaction, as presented in the survey of glove-based systems in [13]. The v-Glove is made of micro fiber and has been tailored to ensure a proper size for a larger number of users as presented in Figure 6(a). The choice of fabric took into account its thickness and flexibility as it is crucial that the glove does not restrict the movement of the users' hands or their ability to handle a tracked wand without having to take of the glove. It is important that the glove do not warm the user's hand, even considering being used in temperature control environments. Additionally, the black color helps the contrast of the optical tracking system.

The XBee module mounted in the v-Gove is configured as a receiver. Another identical module was connected to the control station via USB port, configured as a transmitter. Upon detecting a touch event, the application executed by the control station sends a command to the transmitter XBee, which then forwards it to the receiver XBee attached to the v-Glove.

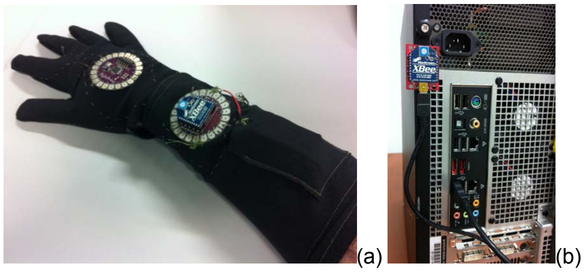

(a) (b)

Figure 6 . (a) v-Glove Prototype, (b) Modem in the Control Station.

The electronic components responsible for the tactile feedback sub-system were tailored on the glove. The stitching of the components was done using a sewing line with conductive properties specially created for this purpose. The seam line is silver-plated and has electrical resistance of approximately 45 Ohms per meter. Figure 7 shows the schematic circuit stitched on the v-Glove.

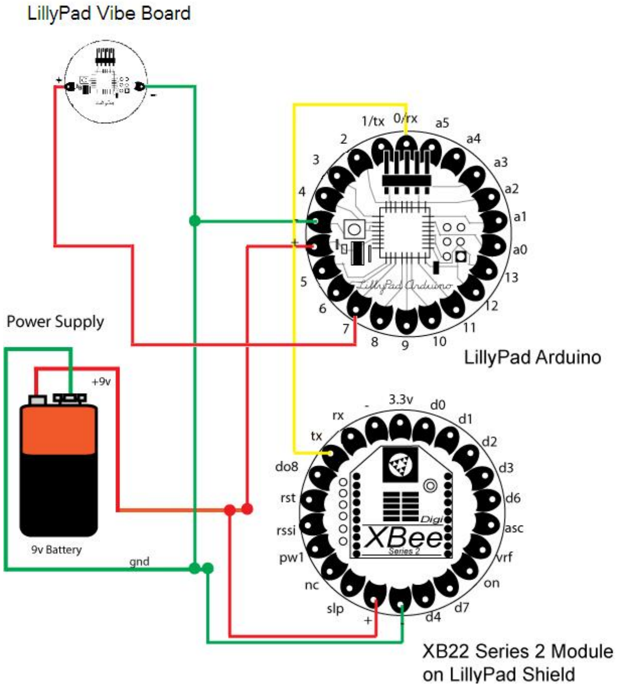


Figure 7 . V-Glove Circuit Diagram [14].

A 9V battery provides power for all components of the circuit. The XBee modem receives through its antenna the commands from the XBee modem transmitter. The command is then sent to the transmit port (Tx) which is connected directly to the receive port (Rx) of the Lilypad Arduino microcontroller. The software stored on the micro-controller receives this information and sends signals to pin number 7, which is directly connected to the vibe board. Activating this device causes in the user a feeling of a slight vibration in the fingertip. The duration of vibration may be controlled.

1) Application running in the microcontroller

The program that runs in the Arduino is called "sketch", and is written in a programming language similar to C. The structure of a sketch can be divided into three parts: an area for declaration of variables and functions created by the user; the setup() function; and the loop() function.

Setup function is the first to be called when the program starts. It can be used for the initialization of variables and controller ports or for loading third-party libraries. The setup function is executed only once, at startup or when the board is reset. Loop function is called continuously during program execution. The first execution of this function occurs only after the end of the setup function. Below is a simplified sketch with the source code used in the v-Glove:

```
1        int finger1Pin = 7;
2        int incomingByte = -1;
3
4        void setup()
5        {
6          Serial.begin(9600);
7          pinMode(finger1Pin, OUTPUT);
8          Serial.flush();
9        }
10
11       void loop()
12       {
13         if (Serial.available() > 0)
14         {
15           incomingByte = Serial.read();
16
17           if (incomingByte == '1')
18           {
19             digitalWrite(finger1Pin, HIGH);
20             delay(300);
21             digitalWrite(finger1Pin, LOW);
22           }
23         }
24       }
```

Line 1 makes the declaration of variables related to the port of the Arduino microcontroller used (in this case port number 7). Line 2 declares the variable used for reading bytes from the serial port. Lines 6-8 define the mode of operation for the ports used as output.

Line 13 runs the code block if there is information to be read into the serial port, which are read in line 15. Line 17 performs the following blocks of code if the byte read is 1. Finnaly lines 19-21 write in the output port a signal of high voltage (5V), waits 300 milliseconds and removes the signal from that port.

2) Finger identification

In order to track the finger position an infrared optical tracking solution is used. Among several options evaluated, the 8910 3M reflective tape was selected as an infrared marker. This tape is widely used as an element of urban signs for its high reflective properties for visible light and its high flexibility (for example it can be easily tailored to uniform traffic agents).

Then, at the tip of the index finger of the glove is applied the 3M retro-reflective tape. This tape has the property of reflecting light with greater intensity in the direction of the illuminating source. So it is possible to efficiently reflect IR to the camera if an illuminator is positioned close to the cameras. The IR cameras capture the light reflected by the tape and estimates the position of the user's finger. As the proposed system uses two perpendicular IR cameras, it is important that the retro-reflective tape is visible by both cameras, then the most appropriate way to position the tape to ensure good visibility is getting them involved in the fingertip. The positioning of the cameras in relation to the user and the tape applied on the glove are shown in Figure 8.

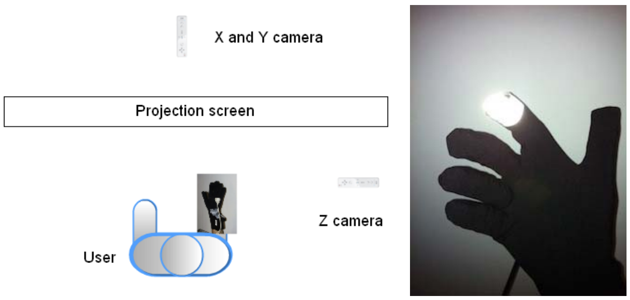


Figure 8 . Set-up of cameras and tape applied on the glove.

B. Tracking

The main advantages of using the WiiMote instead of a conventional camera are: it is wireless, already has a built in IR filter and have development libraries that provide the X and Y coordinates of the IR points captured. A disadvantage of the WiiMote is that it is able to identify only four points of infrared light simultaneously, which may limit an application that is intended to track all the fingers. This will not be a problem in our case, since the proof of concept proposed in this research only uses the index finger.

As the camera of the WiiMote provides the coordinates of the points in a two-dimensional plane, we add a second camera positioned laterally to capture the depth axis. Thus two perpendicular cameras compose the final solution.

The first camera is responsible for tracking the axes X and Y. It indicates the position of the user's fingers on these two dimensions. The second camera is responsible for the Z axis and it is positioned at the side of the user and maps the virtual touch surface. When the user's index finger approaches the mapped plan, the software recognizes a touch on the surface and triggers an event of tactile feedback to the v-Glove, vibrating the user's finger.

Other tracking algorithms using epipolar geometry for instance were evaluated [15]. They are very useful for tracking complex objects with multiple markers on it, but require several calibration steps. For this research, only a single point is necessary, therefore the ortognal WiiMote cameras placement provides a more practical solution. One advantage of the perpendicular cameras is that even if the aligment of the cameras is not perfect the system will continue to work.

1) Infrared Illuminator

The infrared camera present in the WiiMote is only sensitive to a certain intensity and wavelenght of infrared light. Considering that this application will be used in an immersive environment with low light, an infrared illuminator component is essential. The prototope created consists of eight infrared LEDs of 5mm and a dominant wavelength of 940nm fed by a power supply of 12 volts. The LEDs used are of the same type used for remote control devices, and can be easily found in electronics stores. This component generates infrared light that is reflected by the retro-reflective tape on the v-Glove and then captured by the WiiMote cameras.

An alternative to using an infrared illuminator is the placement of the LEDs directly at the tip of the glove fingers, instead of the retro-reflective tape. In this case the camera of the WiiMote would directly capture the light emitted by the LED. The problem with this approach is that the presence of LEDs on the glove increases the battery consumption, thus reducing its autonomy.

The LEDs used were evaluated to make sure the Infrared emision is not harmful to users, and the values calculated are far below those considered hazardous.

C. Control Station

The control station of the tracking system and tactile feedback is a regular PC where the software developed executes. This system is responsible for caculating the coordinates X, Y and Z, as well as to activate the tactile feedback subsystem. In addition, the software can interact with the final applications in the immersive environment.

V. SOFTWARE ARCHITECTURE

The software architecture was divided into five main modules that interact to provide all the features necessary for the v-Glove operation. The application to validate the proposal was developed in Java. Third party libraries were used and they are mostly open source or have consent for use in non-profit research projects like this one.

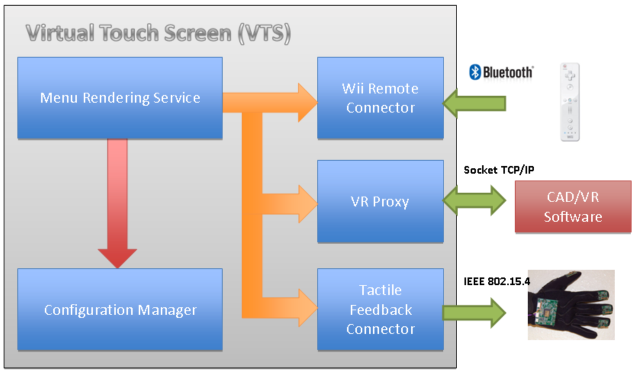


Figure 9 . Software Architecture Diagram.

The architecture diagram of Figure 9 shows the main modules and the external components which they interact, indicating in each case the protocol used. The VR proxy component interacts with the VR/CAD application through a TCP/IP connection. The Wii Remote connector performs its communication via the Bluetooth protocol, while the Tactile Feedback connector communicates with the glove through the ZigBee protocol (IEEE 802.15.4).

A. Menu Rendering Service

This component can be defined as the central module of the application, once it is the first to be executed and it triggers the execution of the modules responsible for the integration with external components of the system. The

Menu Rendering Service is also responsible for building the graphical user interface.

B. *Wii Remote Connector*

This module is responsible for communicating with the WiiMote to capture information from the infrared cameras. The software uses the WiiRemoteJ library [16] to connect to the WiiMote. The library is written in Java and uses the BlueCove Bluetooth driver version 2.1.0 [17]. A listener interface is used for receiving the IR coordinates used by the application.

C. *VR Proxy*

This component is responsible for the abstraction of the CAD/VR application being used and the VTS (Virtual Touch Screen) application modules. It defines a standard interface VRProxy that should be implemented by all VR proxies supported.

When starting the software, the MenuController class initializes all components of the VRProxy. An instance of the CAD/VR application is returned and the proxy is started, causing a new process to be created in the operating system to execute the application. When a user clicks on a menu option in the application, a graphical user interface event is generated. This event is handled by the MenuController class that forwards the execution of the command associated with the event to a VRProxy implementation, causing the command to be executed by the CAD/VR application.

D. *Tactile Feedback Connector*

This component is responsible for generating the haptic feedback that provides the user the sensation to be actually touching a surface by the glove. It has been designed to support several strategies for tactile feedback.

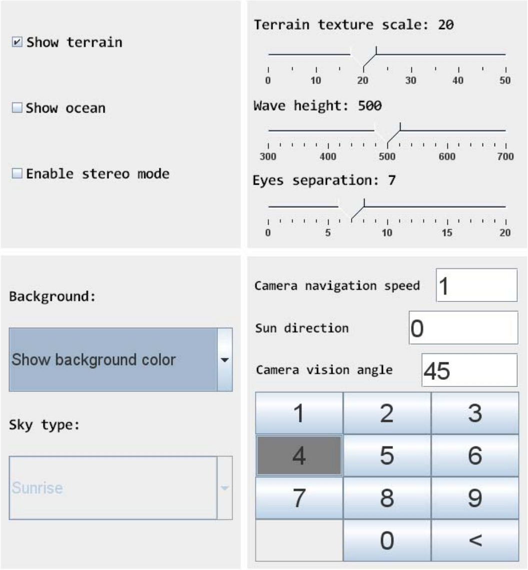
When the user finger reaches the virtual touch interface, a vibration event is triggered through the Tactile Feedback Connector, which sends the command indicating which finger should vibrate using a serial connection to the control station Xbee. The Xbee modem then forwards the command to the v-Glove.

E. *Configuration Manager*

This module is responsible for managing the sustem configuration parameters. The Configuration Manager can be accessed by any class that needs access to application configuration parameters.

VI. MENU AND WIDGETS INTERFACES

In order to evaluate the usability of the v-Glove, a case study was prepared targeted at a CAD application [18]. A list of graphical user interface components was classified and prioritized according to their use in the CAD application, resulting in the following ones: button, checkbox, slider, combobox and text box. These components were then adapted for its use with the v-Glove. Figure 10 shows the resulting components in the application menus.



☑ Show terrain

☐ Show ocean

☐ Enable stereo mode

Terrain texture scale: 20

Wave height: 500

Eyes separation: 7

Background: Show background color

Sky type: Sunrise

Camera navigation speed 1

Sun direction 0

Camera vision angle 45

Figure 10 . Widgets Developed for Evaluation Tests.

A. *Mouse Pointer*

As a way to complement the tactile feedback, a change in the behavior of the mouse pointer was performed. Depending on the distance of the v-Glove over the touch interface, the pointer on the screen change its colors. Figure 11 shows possible colors of the pointer.

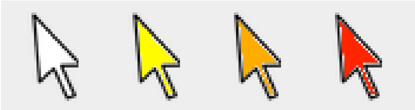


Figure 11 . Pointer colors.

The color of the pointer remains white while the glove is out of range of the camera or when a distance is more than 400 camera pixels from the touch area. The color changes to yellow when the distance is between 200 and 400 pixels, and orange when the distance is less than 200 pixels. The pointer turns red when the user hits the touch area.

VII. EVALUATION

The v-Glove was evaluated using the CAD model presented at Figure 12. This evaluation had three groups of participants with different profiles regarding development and use of 3D applications.

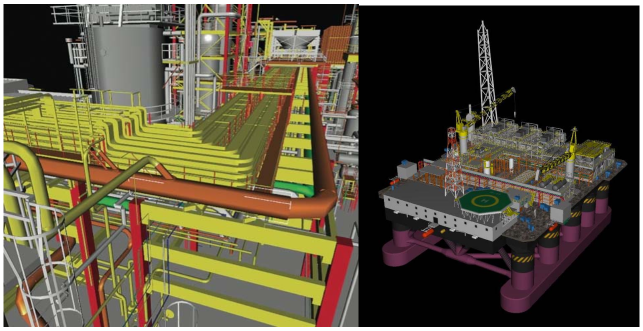


Figure 12 . Virtual Reality / CAD Application.

CAD applications are usually designed for use on the desktop, and are not fully adapted for immersive environments, since their menus and controls are based on the standard WIMP style. All interaction with the software is done through 2D menus and controls (Figure 13), which required an adaptation of context for its use in the interaction paradigm presented here.

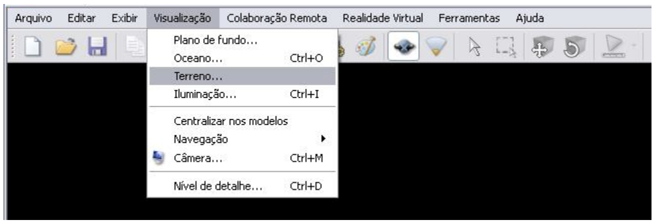


Figure 13 . CAD Application Menu Interface (in Portuguese).

The CAD application menus and widgets were then adapted in a more suitable format for interaction with the v-Glove in an immersive environment (Figure 10). This adaptation occurred only in the relevant components for the evaluation performed during this research.

A. Participants Profile

The age of the participants ranged from 21 to 60 years, TABLE I. shows the average age of participants per group. From the eighteen participants, sixteen were male (89%) and two were females (11%). All participants were right handed and had the habit of using the mouse with their right hand. This is an important point to be observed, since the v-Glove prototype was designed for right hand only.

Users were divided into three groups of equal size, according to their prior experience in 3D applications: Group E was composed by system analysts who work for at least 6 months in the development of the CAD/VR application used; Group O was composed by systems analysts with some experience in software development for computer graphics; Group N was composed by individuals without experience in developing or using graphical software.

TABLE I. USERS AGE.

	Age Average	Younger	Older
Global	29	21	60
Group E	25	22	28
Group O	31	26	37
Group N	31	21	60

94% of the participants had indicated having some experience with 3D applications, like: games, 3D modeling tools and CAD viewers. All users in Group O mentioned some knowledge of the CAD/VR tool, but only a superficial contact and not being part of developers or users group.

B. Resources

The simulation room has two ProjectionDesign evo22sx+ projectors configured in passive stereo through a circular polarizing filter with a 120" anti-depolarizer screen. The computer used has a NVIDIA Quadro FX 4600, an 3.2 GHz Intel Core i7 processor with 12 GB of RAM. Figure 14 shows the room.

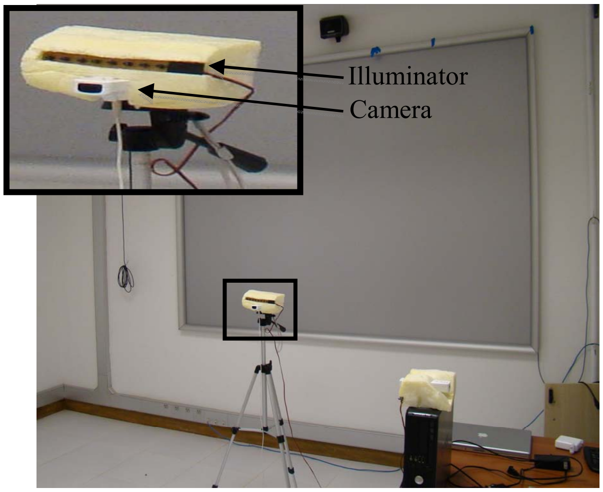


Figure 14 . Evaluation Facility.

C. Evaluation Procedures

A pilot test was conducted with users with characteristics of "Group N", since it is expected to observe more difficulties in the participants of this group, helping to improve the evaluation process. The main experiment was evaluated by two questionnaires, one before and other made immediately after the simulation. The examiner completes an accompanying sheet during the operation. All participants filled in and signed a consent form that explain the purpose of the tests, their role in the process and provides the option of quiting it at any time if they wished.

The evaluation was divided into three sequences of five tasks to be performed by participants using different devices in each sequence. One sequence is performed with the v-Glove with tactile feedback feature turned on, the other without the use of tactile feedback and the other sequence performed with a gyroscopyc 3D mouse [19].

The five tasks for each sequence are the same, based on the menus in Figure 10. In the first task the user was asked to navigate in a CAD scene and look for a particular object, having to select it. In the second task, the user should select one of the checkbox options and confirm. The third task involved the selection of combobox options. The fourth task was to select the required value in a slider-type control, and in the fifth and final task, the user should correct the value typed into a textbox, entering a new numeric value and selecting the finish button.

After concluding the sequence of tasks, the interaction device is changed and the sequence is repeated. This was done in a random order to avoid annoying the user having to perform exactly the same sequence of tasks every time. In order to reduce the learning effects between tasks, the order of use of the devices did not repeat among users of a same group. Considering that there were three devices and six users in each group, it was possible to determine a different order for each user within the group.

VIII. RESULTS

Tullis and Albert [20] present ten usability study scenarios and the related usability metrics that apply to each type of study. According to their classification, the present research fits into the "comparison of alternative designs" and five metrics are applyiable: task success, task time, issue-based metrics, self-reported metrics and combined and comparative metrics.

A. *Task Success*

The first analysis has been done on the data captured about the success or failure in performing the tasks required. Most users have no difficulty in completing the tasks. 100% of users completed the tasks performed with the 3D mouse while using the glove with tactile feedback the success rate of task 2 was 89%, and when the glove without tactile feedback was used the success for tasks 2 and 3 were 94%.

B. *Task Time*

The average task for each group is presented in Figure 15. The glove without tactile feedback has the worst average performance, followed by the glove with tactile feedback and finaly the 3D mouse. Moreover, the time to accomplish tasks decreases as the level of experience in 3D of the users.

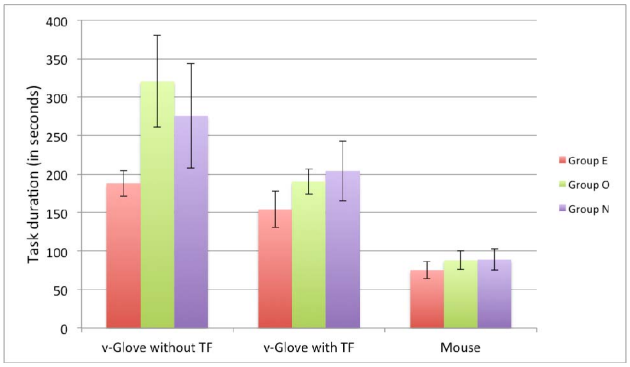


Figure 15 . Task Time Average per Group.

C. *Issue-based Metrics*

During the experiment, the evaluators collected information on situations that occurred during the execution of tasks. The issues were classified by frequency, priority (high, medium or low), category and rating (frequency + priority). The main problems were:

- Lack of accuracy when moving the hand in Z direction – when moving the hand to reach the virtual touch surface it is dificult for the user to prevent variations in the X and Y axis. For this reason, when the pointer reaches the click area its position might be different from the original one, causing the click to be performed in a different location than the expected;
- Lack of precision in the slider widget with the glove - users reported difficulties to place the slider indicator in the correct position. This happens because, depending on the scale used, the distance between two markers on the rule was small enough so minimal variations in finger position prevent its placement in the desired location;
- Fatige in the arm and hand - the suggested position to use the v-Glove requires the user to keep its arm raised, causing some users to complain about fatigue in the arm and hand;
- Difficulty to differentiate orange pointer from red - users reported difficulties to notice the difference between pointer colors orange and red, resulting in perception issues in the visual feedback, specially when using the v-Glove without tactile feedback.

The results of the usability issues metric indicate that 58% of issues observed during the tests are related to problems in the operation of the interaction devices. Regarding the percentage of the usability issues, only 7% of are unique to the mouse, while 72% happens in either versions of the glove. The remaining 21% refer to issues observed in both devices, like posture problems or fatigue situations.

D. *Self-reported Metrics*

From the data collected in interviews, it was possible to examine self-reported metrics quantitatively and qualitatively. Completion of the questionnaires with questions on the Likert scale [20] is the basis of quantitative analysis presented below.

1) *Quantitative Analysis*

Figure 16 shows the mean score for each device usability, where the 1 means "very bad" and 7 "very good". The results of the analysis were consistent with results observed in the task duration metrics. The v-Glove without tactile feedback was the worst, followed by the glove with tactile feedback and the 3D mouse.

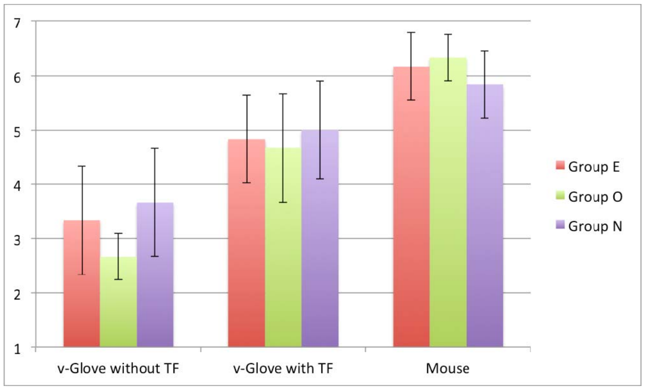


Figure 16 . Mean Points per Group.

2) *Qualitative analysis*

Since most of the users have some experience in working with graphical software, during the interviews we captured contributions from the participants. The four most common suggestions were:

- Increase the scale of the movement relative to the pointer on the screen;
- Use the click of the first contact with the touch area;
- Detect the click from a minimum variation in the Z axis after reaching the touch area;
- Decrease the intensity of vibration

E. Final Discussions

The task success metrics did not provide any significative discoveries once the tests were designed in a way the users would not have difficulties to complete tasks. The few cases where users could not complete tasks were caused by accidental selection of the wrong option and are not relevant for this study.

The task time metrics, on the other hand, provided information with statistical relevance confirming that there are differences in task duration average for different devices. Despite a slight tendency towards a better performance according to the level of 3D experience of the users, the analysis of variance (ANOVA) of two factors with replication determined that this difference has no statistical significance when comparing the performance of one group over the other ($F(3.20) = 2.56$, $p < 0.09$). The same technique also confirmed that the time differences between the devices are indeed significant ($F(3.20) = 19.19$, $p < 0.01$), confirming the results obtained in earlier observations, when the mouse was expected to have the best performance followed by the v-Glove with tactile feedback.

Based on the results of the usability issues metrics it’s also possible to foresee that some effort focused in reducing the usability issues related to the v-Glove might result in improvements in the glove indicators compared to the mouse.

The tactile feedback had also a considerable impact in the v-Glove. The idea behind the inclusion of two versions of the v-Glove in the tests was to study the influence of the tactile feedback in the glove usability. The results of the ANOVA (two factors with replication) in the comparison of the user performance indicates a relevant statistical difference in favor of the v-Glove with tactival feedback ($F(4.17 = 5.23$, $p < 0.03$).

IX. CONCLUSIONS AND FUTURE WORK

In this work, we proposed and developed an interaction device for immersive virtual reality environments, called v-Glove. The v-Glove is a glove that allows a user to interact with virtual reality applications in a natural way through the movement of the hand in 3D space. The selection and manipulation of objects is done by bringing the hand to a touch area mapped in the virtual space. As proof of concept, an application capable of interacting with CAD data was adapted for an immersive environment. We conducted a usability study of the glove with quantitative and qualitative assessments with three groups of users with different profiles of 3D knowledgment.

The use of gloves as an element of control pointer on the screen is more intuitive than the mouse itself, but because the interaction tasks supported by windowing applications have already been mapped to a 2D model to facilitate its use with the mouse, the graphical user interface have to be adapted. Applications designed for the standard WIMP can hardly be used in such an environment without some kind of adaptation.

Regarding the graphical user interface components studied, we found that the slider widget is the hardest to be adapted, regardless the device used for interaction. In the combobox component some interaction problems were also identified, since the user requires at least two clicks to select an option. Alternative formats as those proposed by Gerber and Bechmann [21] and Dachselt and Ebert [22] might be considered. These authors suggest the adoption of respectively a ring menu and a cylindrical menu (called collapsible cylindrical trees).

During the evaluation of the tactile feedback it was noted that this is indeed essential to the v-Glove operation, a result confirmed in comparative testing of the glove with and without this feature. Some improvements can still be made to this functionality, such as support to the varying intensity of the vibration and the progressive implementation of tactile feedback to better fit the user expectations.

A. Future Work

One of the most important features to be included is the support to multi-touch interaction and feedback. Recognition of gestures for the interaction tasks is another important feature to be considered. A more complete second glove is being produced to be used for left hand users and also allowing interaction with both hands simultaneously. This will improve the interactions, especially for tasks such as manipulating 3D objects in the scene. Once the 3D mouse used in our evaluation is a commercial product, we are also considering to build the v-Glove over a commercial haptic glove as the one provided by [23].

Another resource planned is the clicking through the movement of pinch between the thumb and fingers, as found in the pinch gloves [24]. The glove would have to be modified including two electrical contacts at the thumb and index fingertips to close a circuit when in contact with each other.

The system is also being ported to a highly immersive system [25]. Due the larger dimensions, new studies are being conducted in order to better find a position for the WiiMotes, not ocluding the user view (Figure 17).

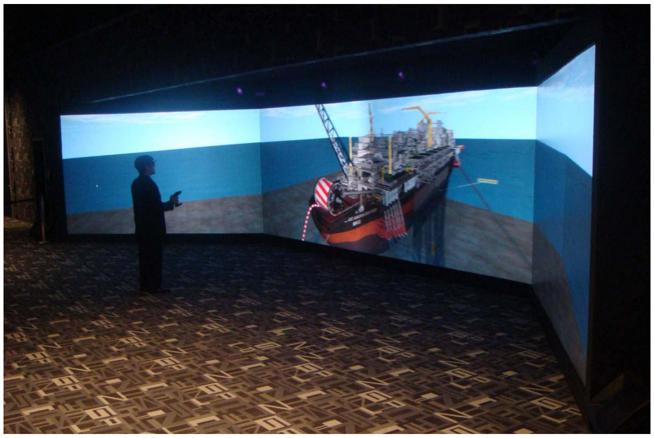


Figure 17 . High Immersive System Being Tested.

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