Virtual Reality Techniques for 3D Data-Warehouse Exploration

Hamza Hamdi, Eulalie Verhulst and Paul Richard
Laboratoire Angevin de Recherche en Ingénierie des Systèmes (LARIS - EA 7315), Université d'Angers, Angers, France

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Abstract: This paper focuses on the evaluation of virtual reality (VR) interaction techniques for exploration of data warehouse (DW). The experimental DW involves hierarchical levels and contains information about customers profiles and related purchase items. A user study has been carried out to compare two navigation and selection techniques. Sixteen volunteers were instructed to explore the DW and look for information using the interaction techniques, involving either a single Wiimote^{TM} (monomanual) or both Wiimote^{TM} and Nunchuck^{TM} (bimanual). Results indicated that the bimanual interaction technique is more efficient in terms of speed and error rate. Moreover, most of the participants preferred the bimanual interaction technique and found it more appropriate for the exploration task. We also observed that males were faster and made less errors than females for both interaction techniques.

1 INTRODUCTION

Worldwide corporations are mining their data to learn about client purchasing patterns, fraud, credit applications and health care outcome analysis. It appears that the worldwide business intelligence and data warehousing market had about a 60% year-over-year growth. As one expects, there has been a surge in the number of applications that provide DW creation, management and mining. A DW is a subject-oriented, integrated, time-variant and non-volatile collection of data in support of management's decision making process (Han and Kamber, 2000).

During the last decade, significant research efforts have been devoted towards facilitating access to information. In this context, typical relational database systems were optimized for query processing and online transaction processing (OLTP), which minimizes the time needed for systematic daily operations of an organization (Sawant et al., 2000; Ammoura et al., 2001). VR techniques were also proposed to immerse experts in 3D DW. This approach relies heavily on the human abilities to explore, perceive, and process 3D information. In this context, different VR setup and application have been developed (Valdés, 2005; Ogi et al., 2009; Nagel et al., 2008). Most of these involved complex systems and user interfaces such as the CAVE^{TM} (Cruz-Neira et al., 1992). With the continuous improvements in computer technology and video games, it is now possible with almost standard PCs and low-cost interaction devices such as the Nintendo Wiimote^{TM} to explore 3D data sets. However, usability studies and human performance evaluation still need to be carried out in order to reach intuitive and efficient interaction techniques.

In this paper, we report on a user study aimed to compare two different interaction techniques for the exploration of a data warehouse with specific graphics encoding. Sixteen volunteers were instructed to look for information using an interaction technique involving either a Wiimote^{TM} (monomanual technique) or both a Wiimote^{TM} and a Nunchuck^{TM} (bimanual technique).

In the next section, we give a short survey about VR techniques used in the context of Visual Data Mining (VDM). Then we describe some works about 3D interaction techniques in Virtual Environments (VEs). In section 3, we describe the experimental data set and the proposed graphic encoding of these data. Section 4 presents the proposed interaction techniques based on the Nintendo Wiimote^{TM} and Nunchuck^{TM}. Section 5 is dedicated to the experiment and the results analysis. The paper ends by a conclusion and gives some tracks for future work.

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2 RELATED WORKS

2.1 Visual Data Mining

Visual data mining (VDM) aims to integrate the human in the data exploration process, applying his perceptual abilities to the large data sets available in today's computer systems. The main idea of VDM is to present the data set in some visual form, allowing the human to get into the data, draw conclusions, and directly interact with the data. VDM techniques have proven to be of high value in exploratory data analysis and they also have a high potential for exploring large databases. According to (Wong and Bergeron, 1997) the exploratory analysis of data and VDM are not only a set of tools but also a philosophical manner to approach the problem of knowledge discovery.

VDM methods have been implemented in VR in several occasions as well as traditional methods for data exploration (Symanzik et al., 1997; Wegman and Symanzik, 2002). In 1999, a research project called 3D Visual Data Mining (3DVDM) was initiated at the VR Media Lab at Aalborg University to study how VR may be used in VDM (Nagel et al., 2001; Granum and Musaeus, 2002). Among the facilities of the VR Media Lab are a 3D Power Wall, a 160 degree Panorama, a 6-sided CAVE, and a 16 processor SGI Onyx2. Another project called DIVE-ON (Data mining in an Immersed Virtual Environment Over a Network), uses advance in VR, databases, and distributed computing to experiment with a new approach to VDM. For example, the DWs generated by DIVE-ON were N-dimensional data cubes (Ammoura et al., 2001).

2.2 3D Interaction Techniques

3D interaction techniques are generally classified as follows (Mine, 1995; Hand, 1997; Zeleznik et al., 1997): selection, manipulation, navigation and application control. Navigation is composed of two tasks: travelling and way-finding (Bowman et al., 2001), where travelling represents the main component of navigation and refers to the physical displacement from a place to another one. Way-finding corresponds to the cognitive component of navigation by allowing the users to be located in the VEs and to choose a trajectory for displacement. Both aspects of navigation are crucial for efficient exploration of 3D DW.

Several studies aimed to develop techniques for specific tasks and applications. (Bowman et al., 1997) suggested a framework for evaluating the quality of interaction techniques for specific tasks in VEs. Results indicated that pointing techniques are advantageous relative to gaze-directed steering techniques for a relative motion task. Moreover, they observed that motion techniques which instantly teleport users to new locations are correlated with increased user disorientation. Some hand directed motion techniques have also been proposed for navigation. The position and orientation of the hand determines the direction of motion through the VEs. Wii devices have been adopted by a number of researchers for a wide variety of applications (Schlomer et al., 2008). Generally, in case of using The Wiimote^{TM} for navigation, rotation angles such as pitch, yaw, and roll information are used. For example, (Duran et al., 2009) used the Wiimote^{TM} for controlling wheelchair using pitch and yaw movements. (Fikkert et al., 2009; Fikkert et al., 2010) proposed interaction techniques using the Wiimote^{TM} and the Wii Balance Board^{TM}. Both input devices were used to navigate a maze application. (Yamaguchi et al., 2011) developed a 3D interaction technique to explore Google Earth using the Nintendo Wii devices. The Wiimote^{TM} was used for zooming and steering and the Balance Board^{TM} was used for walking. The authors tested operation workload for 9 different threshold angle combinations. They found a most low workload threshold angle combination of 45 degrees (for zooming out) /-15 degrees (for zooming in) and of 30 degrees (for steering right) /-30 degrees (for steering left). Some more recent approaches have been proposed for navigation in VEs (Fajnerova et al., 2015; Gaona et al., 2016; Christou et al., 2016).

3 DATABASE AND GRAPHIC ENCODING

The aim of the graphic encoding is the rewriting of the data in the form of graphic objects by associating each variable in the data with a graphic ones (position, length, surface, color, luminosity, saturation, form, texture, etc.). Graphic objects can be from zero to three dimensions, i.e. a point, a line, a surface, or a volume. Evolution of the objects in time can introduce an additional dimension. Several authors worked with the classification of the graphic encodings so as to determine those which are most effective according to the data to represent. For the statistical graphs (groups of dots, diagrams, etc), there are works from(Cleveland and McGill, 1984), and(Wilkinson, 1999).

3.1 Description of the Database

For the experiment, we modelled a simple management of client relationship (CRM) database that gather information enabling the describtion and characterization of customers purchase. This database is primarily characterized by:

- the *Customer* table that is characterized by the identifier, first name, family name, age, sex, marital status and the number of credits;
- the *Product*, table where each product is identified by a single code and is indicated by the wording, the category of product (fruits, vegetables, drinks), the unit price and stock.

This database is described under the Microsoft Access basic management system, and include 200 customers. The Figure 1 illustrates the selected database using the relational model.

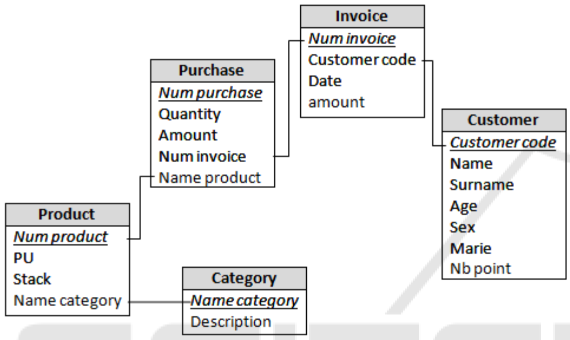


Figure 1: Model of data design.

3.2 Graphic Encoding

Each element of the database was translated to a graphic representation (position and size). The proposed graphic encoding of each customer is illustrated in Figure 2. The height of the cone represents the number of purchased items, while the radius of the sphere represents the percentage of the expenditure relativelly to the other customers. The color of spheres and cones were randomly selected in order to easily distinguish each customer. More precisely, a large cone posed with the lower part of a sphere represents a customer whose expenditure is high, while a small cone posed with the lower part of a sphere represents an encoding of a low expenditure customer. Moreover, complementary text labels are posted above each object to give the first name and familly name of the customer.

Each customer has been placed on the right (females) or left (males) side of the VE according to his/her gender (Fig. 3 (a)). As we can see, this graphic encoding strongly highlights the most active customers. Similarly, the customers have been placed at different depth according to their age, as illustrated in Table 1. The database contains all information about customers' purchases history (last twelves months only) which have been classified according to their categories (cloths, fruits, meat vegetable, yoghurts, fish, cheese, drinks). These data are visualized using three-dimensional histograms representing the amount of each product versus the month they have been purchased. The histograms are positioned similarly to the shelves of a supermarket (Fig. 3 (b)).

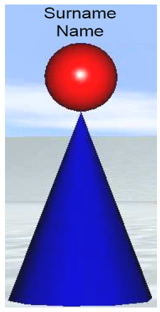


Figure 2: Graphic encoding of each customer.

Table 1: Custumers segmentation according to their age.

	Gender	
	Males	Females
Age	60-80	60-80
	40 - 60	40 - 60
	20 - 40	20 – 40
	10 -20	10 -20

4 INTERACTION TECHNIQUES

4.1 Interaction Modelling

We proposed two interaction modes for the exploration of the data-warehouse: (1) the navigation mode and (2) the selection mode. The navigation mode allows the user to navigate and explore both the VE containing the customers representation and each VE containing the customers data. This appoach is illustrated by the hierarchical model presented in Figure 4.

- The *Translate* function allows the user to move the camera (viewpoint) along the lateral axis and/or the depth axis;
- The *Zoom* function allows the user to zoom on a selected customer, whatever his/her distance from the user;
- The *Rotate* function allows the user to rotate the camera relative to the vertical axis (steering).

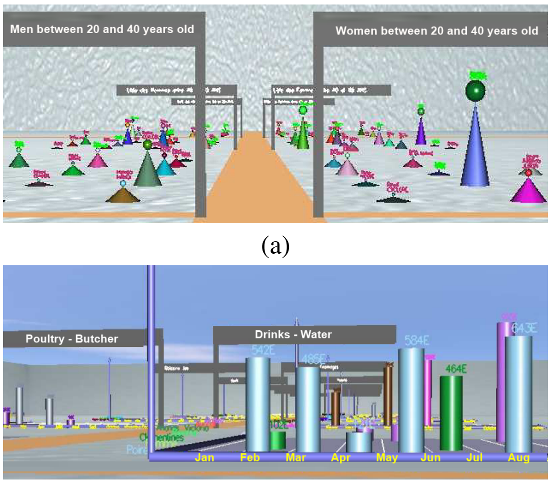


Figure 3: Illustration of the 3D database: customers visualization (a), purchased items of a given customers (b).

The selection mode is split in three sub-modes including *Pre-selection*, *Entry*, and *Exit*. It allows the user to select a given customer at any time and at any distance from him/her. This mode is illustrated by the hierarchical model presented in the Figure 5.

- The *Pre-selection* function enables an automatic zoom on a selected customer in order to quickly and easily get his/her personal information;
- The *Entry* function enables the user to be teleported in the VE containing the selected customer personnal data;
- The *Exit* function enables the user to get back to the main VE. This function could be activated at any time and anywhere in the VE containing the customer personnal data and do not require any selection process.

4.2 Implementation of Interaction

In order to propose a low-cost system, we implemented the interaction technique using the Wiimote^{TM} and the Nunchuck^{TM}. The Wiimote^{TM} (Fig. 6) has the capability to track the user's hand orientation along two degrees of freedom (pitch and roll) using inertial sensors (accelerometers / gravimeters). In addition, the Wiimote^{TM} has 12 buttons which could be used to trigger events. The Wiimote^{TM} is also equiped with an infrared emitter which could be used to track yaw movements. The Wiimote^{TM} communicates with the computer using Bluetooth wireless communication an could be connected with the Nunchuck^{TM} in order to add a second set of 3 accelerometers along with 2 trigger-style buttons and

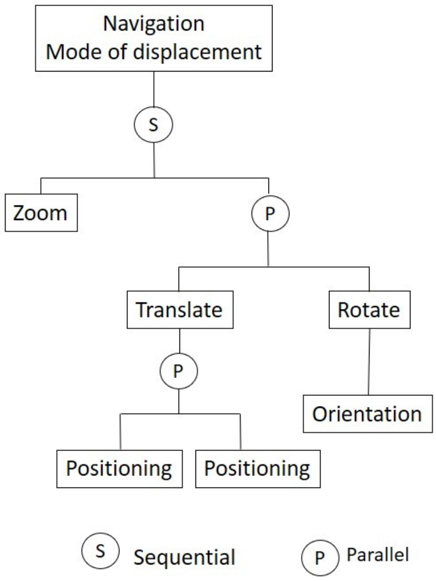


Figure 4: Hierarchical model for the navigation mode.

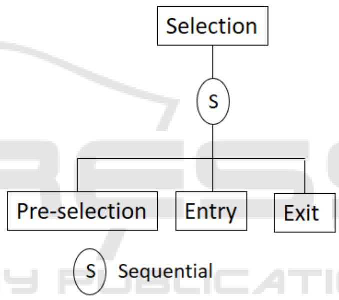


Figure 5: Hierarchical model of the selection mode.

an analog joystick. therefore, the combination of the Wiimote^{TM}/Nunchuck^{TM} may be used as a bimanual user input.

4.2.1 Mono-manual Interaction Technique

For this approach, the Wiimote^{TM} was used to carry out forward and backward movements (pitch) and steering movements (roll). It was also used to switch between the navigation and the selection modes (B button). This approach allows simultaneous control of translation and rotation of the virtual camera. In the selection mode, the mouse cursor was also moved using the pitch and roll movements preventing the use of the infrared emmiter/receiver. To select a given customer and trigger the teleportation of the user in the VE containig his/her peronnal data (customer world), the A button of Wiimote^{TM} was used.

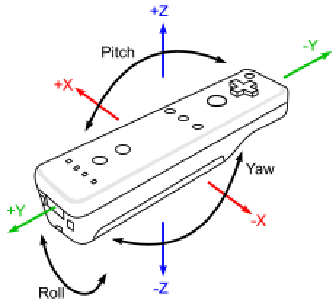


Figure 6: Rotational degrees of freedom (pitch, roll and yaw) provided by the Wiimote^{TM}.

4.2.2 Bi-manual Interaction Technique

The proposed bi-manual interaction technique use both the Wiimote^{TM} and the Nunchuck^{TM}. The former device is used for only for customer selection and trigger the teleportation and the come back of the user in the main VE. The latter device is exclusivelly used for navigation and therefore to control the forward/backward (Fig. 7 (a)) and steering (Fig. 7 (b)) movements of the virtual camera. This is done using the joystick of the Nunchuck^{TM}. As in the previous navigation technique, this approach allows simultaneous control of translation and rotation of the virtual camera.

(a) (b)

Figure 7: Control of forward/backward (a) and steering (b) movements using the Nunchuck^{TM}.

5 USER STUDY

5.1 Task

Each participant was instructed to explore the customers world and find out the three best customers (higher cones), among one hundred customers. Then, they had to select each of these customers and explore their personal data (customer world) to discover the three most purchased items. This procedure is illustrated in Figure 8 using a finite state machine. The task ends as the participant felt he/she collected the requested information and get back to the main world.

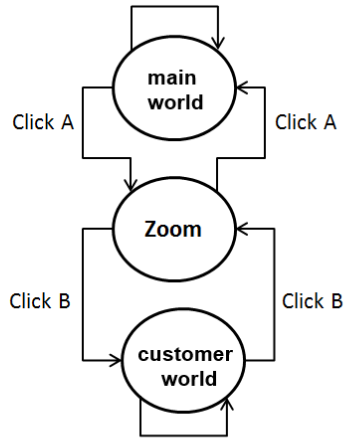


Figure 8: State machine model of the exploration task.

Whatever his/her location, a click on a given customer (using the A button of the Wiimote^{TM}) enables a teleportation of the virtual camera in front of him/her. This allows the participants to read the textual information about the customer's name and give him/her the possibility to be teleported in the customers world. Thus, the participant may then decide to enter in the customer world (using the B button of the Wiimote^{TM}), or to get back to its initial position and continue the exploration of main world. In the customer's world, the participants can navigate using the same interaction technique and find out the requested information (three most purchased items). The participants can then activate the B button of the Wiimote^{TM} to get back to their location in the main world (in front of the previoully selected customer).

5.2 Design and Procedure

Sixteen participants (8 males and 8 females) were divided into two groups ($G1$ and $G2$). They were aged between 22 and 35 years old (72.72% are right-handed and 27.27% are left-handed) and had normal or corrected-to-normal vision capabilities. The experiment was conducted according to the two following conditions:

- $C1$: navigation and selection using Wiimote^{TM} only (Fig. 9 a);
- $C2$: navigation using the Nunchuck^{TM}, selection using the Wiimote^{TM} (Fig. 9 b).

Four different VEs ($D1$, $D2$, $D3$ and $D4$) each corresponding to a different database were defined. The participants of the group $G1$ start the exploration of $D1$ and $D2$ by using Wiimote^{TM} only (condition $C1$). Then, they explore $D3$ and $D4$ by using Wiimote^{TM}

and Nunchuck™ (condition $C2$). Similarly, the participants of the group $G2$ start the exploration of $D1$ and $D2$ by using Wiimote™ and Nunchuck™ (condition $C2$), and they also explore $D3$ and $D4$ by using Wiimote™ only (condition $C1$). In order to facilitate the comprehension of the experience, we give a short description of the task and allow each participant to get acquainted with the system and perform in both conditions ($C1$ and $C2$).

(a)

(b)

Figure 9: A participant exploring the 3D datawarehouse using: (a) the Wiimote™ only (condition $C1$), and (b) both the Wiimote™ and the Nunchuck™ (condition $C2$).

Each participant was placed in front of a large rear-projected stereoscopic screen (2x2.5 m) as illustrated in Figure 9, and equiped with passive (polarized) glasses. A Full HD Optoma HD142X (1080p) projector was used for displaying the images. The participants were instructed to start the task using either the Wiimote™ ($C1$) or both the Wiimote™ and Nunchuck™ ($C2$) according to the group they belong to. At the end of the experiment, we gave each participant a questionnaire in order to get subjective data about the proposed interaction techniques and the graphic encoding of the data warehouse.

5.3 Collected Data

We recorded the task completion time and the number of errors for each single trial for each database ($D1$, $D2$, $D3$, and $D4$). The errors consisted in the wrong selection of the three best customers or the most three purchased items. In order to examine participant's behavior during the task, we recorded the paths for each single trial.

5.4 Results

In this section we present the results of the experimental study. The collected data have been analyzed through a one-way repeated ANOVA. The description of the results is based on three criteria: (1) task completion time, (2) average number of errors (number of best custumers not selected or number of the three most purchased item not selected), and (3) participant's paths, which have been recorded in order to analyse his/her behaviour and strategy or any difficulties concerning the task.

5.4.1 Effect of Navigation Technique

Task Completion Time. The ANOVA revealed a significant effect of the navigation technique on the task completion time ($F(1,23) = 20.19; p < 0.05$). Average completion time for the condition $C1$ and $C2$ condition were respectively about 364.3 Sec. (SD : 36.30) and 300.7 Sec. (SD : 29.75). This result is illustrated in Figure 10.

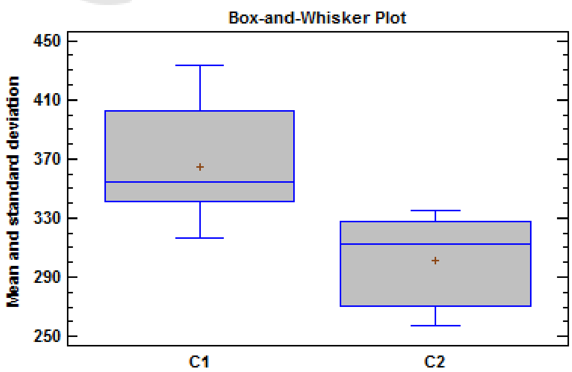


Figure 10: Task completion time (Sec.) vs. condition $C1$ (monomanual) and $C2$ (bimanual).

Number of Errors. The average number of errors for the condition $C1$ (monomanual) and $C2$ (bimanual) were 4.27 and 3.73 respectively. A statistical analysis (ANOVA) showed that the interaction technique, either monomanual or bimanual, has no significant effect on error rate.

5.4.2 Gender Effect

In the following paragraph we look at the gender effect on participant's performance such as the task completion time and number of errors.

Task Completion Time. We observed a significant gender effect on task completion time ($F(1,23) = 42.73; p < 0.05$). Average completion time was about 266 Sec. ($SD : 40.5$) for males and 399 Sec. ($SD : 53.9$) for females (Fig. 11). This suggest that females had more difficulties in exploring the VEs and find out the requested information than males.

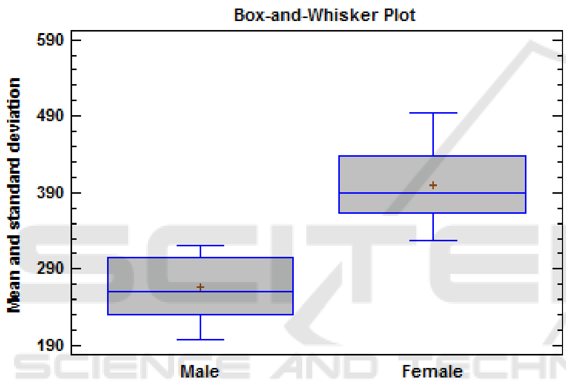


Figure 11: Task completion time (Sec.) vs. gender.

Number of Errors. The number of errors was on average 3.14 for males, and 6.33 for females (Fig. 12). Thus, females made more than twice number of errors than males.

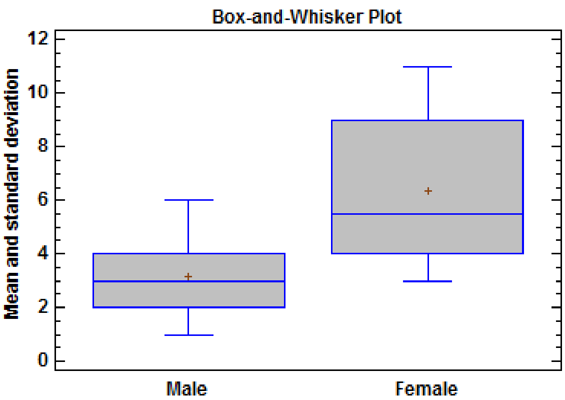
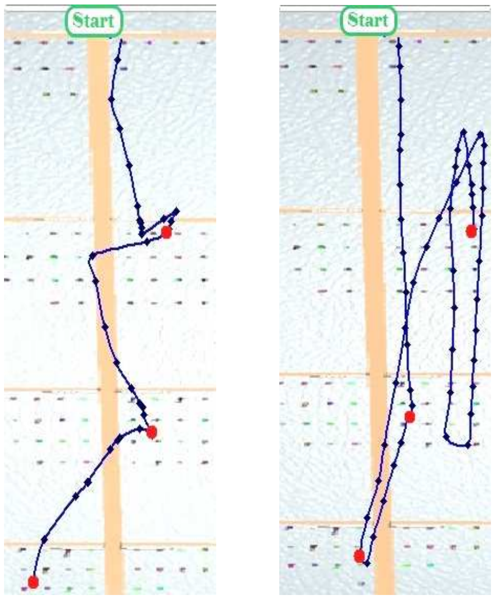


Figure 12: Number of errors vs. gender.

Navigation Paths. Figures 13 (a) and 13 (b) illustrate typical paths associated respectively with males and females. We observed that most females used no-optimal and longer routes than males.



(a) (b)

Figure 13: Typical paths obtained by males (a) and females (b).

5.5 Subjective Data

Each participant were instructed to fill a questionnaire and answer the following questions.

Question 1 Which interaction technique you feel the most relevant for the task?

Question 2 How would you rate the level of difficulty of the task (simple/difficult/very difficult)?

Results showed that many participants found the bimanual interaction technique more relevant than the monomanual one. Thus, 63.63% of them preferred to perform the task using the Wiimote^{TM} associated with the Nunchuck^{TM} and 36.36% of them preferred to perform the task with the Wiimote^{TM} only. Concerning the level of difficulty of the task, many participants (72%) found it simple and had no difficulty to understand the meaning of the graphics.

5.6 Discussion

In this paper we compared mono and bimanual interaction technique for the exploration of a data warehouse. Participants used Wiimote^{TM} alone or Wiimote^{TM} and Nunchuck^{TM}. The results revealed that interaction technique has a significant effects on the objective dependant variables (completion time and error rate). We observed that the bimanual interaction technique (Wiimote^{TM} and Nunchuck^{TM}) led to better performance. In addition, most of participant preferred this technique over the monomanual one (Wiimote^{TM} only).

These results confirm some previous results concerning the efficiency of bimanual interaction technique for complex motor activities (Guiard, 1987). Of course, any combinations of these devices would have been possible like selection with the Nunchuck^{TM} and navigation with the Wiimote^{TM}. However, the use of the Wiimote^{TM} for selection and the Nunchuck^{TM} for navigation is efficient. Indeed joysticks are easy to use(Vera et al., 2007) and only the Nunchuck^{TM} has a joystick. The Nunchuck^{TM} may have a better usability than the Wiimote^{TM}. The observation of paths in the cutomers world revealed that the Nunchuck^{TM} is more appropriate for navigation than the Wiimote^{TM} (less saccadic trajectories). We have observed a significant gender effect on task performance. The males had much better performance in terms of task completion time and error rate than females with both interaction techniques. It seem that this difference come from the difficulties for females to navigate and explore the 3D worlds(Vila et al., 2003). These results allow us to state that 3D perception is relatively low for females (Fig. 13)(Coluccia and Louse, 2004). Futhermore, these difficulties may have been increased by the complexity of the task and the multilevel hierachy of the data warehouse involving back-and-forth transposition between the customer world and the purchased items worlds.

6 CONCLUSION AND FUTURE WORK

In this paper, we investigated the use of VR techniques for the exploration of a data warehouse. In this context, we have proposed two interaction techniques based on the Wiimote^{TM} and Nunchuck^{TM}. Volunteer participants were instructed to explore a data warehouse with specific graphics encoding and collect information, either using the Wiimote^{TM} only for section and navigation (monomanual technique) or using the Nunchuck^{TM} for navigation and the Wiimote^{TM} for selection (bi-manual technique). Results indicated that the proposed bimanual interaction technique is more efficient than the mono-manual one in terms of completion time and errors rate. Moreover, most participants preferred the bimanual interaction technique and find it easier and more appropriate for the required task. Finally, we observed that males were much faster and made less errors than females for both interaction techniques. This confirm previous results concerning the difficulties of females for navigating in complex 3D worlds(Vila et al., 2003). In the future work, we will develop and investigate interaction and navigation techniques such as step-in place. In addition, we will introduce haptic and multimodal assistances to help the users to find information in the data warehouse. We will also pay attention to the usability of the interaction technique and users habits.

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