3D Interaction Techniques for Virtual Shopping: Design and Preliminary Study

Eulalie Verhulst[1,2], Paul Richard[1], Emmanuelle Richard[1], Philippe Allain[2] and Pierre Nolin[3]
[1]*Laboratoire Angevin de Recherche en Ingénierie des Systèmes (LARIS - EA 7315), Université d'Angers, Angers, France*
[2]*Laboratoire de Psychologie des Pays de la Loire (LPPL EA 4838), Université d'Angers, Angers, France*
[3]*Laboratoire de Recherche Interdisciplinaire en Réalité Virtuelle (LARI-RV),*

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Abstract: Virtual Reality is now recognized as a powerful tool for the assessment and rehabilitation of both motor and cognitive impairments. In this context, effective Virtual Environments (VEs) that simulate everyday tasks must be proposed. We have developed a virtual supermarket (VS) in which the user can explore and collect various items using a shopping cart. Four interaction techniques have been designed and compared in terms of usability, performance and workload with healthy volunteer participants. These techniques go beyond the desktop paradigm by offering a more immersive and intuitive way of interaction. Results showed that participants were more efficient in terms of performance (completion time and travelled distance) using the game-pad rather than using full body gestures. However, they had more fun performing the task under these conditions.

1 INTRODUCTION

Virtual Reality (VR) is now recognized as a powerful tool for the assessment and rehabilitation of both motor and cognitive impairments (Merians et al., 2002; Broeren et al., 2002; Flynn et al., 2003; Katz et al., 2005). Indeed, VR provides a unique medium for the achievement of several requirements of effective rehabilitation intervention: repetitive practice, feedback about performance, and motivation to endure practice (Riva, 2003; Gaggioli et al., 2009; Raspelli et al., 2012; Cipresso et al., 2012; Villani et al., 2013; Pallavicini et al., 2013). In addition, VR techniques lead to constantly monitor patient's performance and to quantify his improvements. Another important advantage of VR is related to the benefits of the immersive experience or presence in the virtual environment (VE) (Cipresso et al., 2013; Repetto et al., 2013; Riva et al., 2011).

The most common navigation techniques used for the virtual supermarket (VS) is based on desktop hardware such as a computer mouse, keyboard, or a joystick. However, even if most people usually work or play with a computer mouse or a keyboard, they usually don't use them in an optimal way for navigation tasks (McClymont et al., 2011) and the use of a joystick appears to be more convenient than a keyboard (Vera et al., 2007). Some systems use more complex interaction techniques or expensive devices, and are therefore somehow difficult to set-up outside the lab or in clinical environments (von Kapri et al., 2011; Cruz-Neira et al., 1992; Williams et al., 2007).

To be effective in the context of virtual rehabilitation, VEs and 3D interaction techniques have to be easy-to-use or easy-to-learn. However, although many research has been carried out to make it easier, interacting with VEs is still not straightforward, especially for people with special needs, disabilities or deficiencies. Therefore, more research is needed in this context.

The goal of this research is to provide different navigation and selection techniques ranging from desktop interaction techniques based on the use of joystick or game-pad to interaction techniques based on body gestures. In this context, we have designed and compared different 3D interaction technique in terms of usability performance and workload. The results provide information about different interaction techniques and which aspects of the techniques could bring benefits to users with special needs, disabilities or deficiencies in a context of rehabilitation and training in a VS.

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The paper is organized as following: the next section provides a survey of the related work concerning the use of virtual supermarkets in the context of virtual rehabilitation and the techniques proposed for navigation and selection. Section 3 presents an overview of the developed system, including the description of the virtual supermarket and the proposed interaction techniques. In Section 4, we describe our user study aimed at comparing the proposed interaction techniques. Section 5 provides a discussion concerning the participants' performance (completion time, distance travelled, and errors) and the subjective data collected using questionnaires. Section 6 concludes the paper and discusses directions for future work.

2 RELATED WORKS

2.1 Virtual Supermarkets

During the last decade, researchers have investigated the potentials of virtual supermarkets (VS) to evaluate executive functions in several populations (Elbaz et al., 2009; Josman et al., 2014). In this context, different VS have been developed such as the Virtual Interactive Shopper (VIS) (Hadad, 2012) or the V-Mall (Rand et al., 2009).

Although they have similar configurations, the proposed VS differ in terms of interaction techniques and experimental set-up. For example, Rand et al. (Rand et al., 2005) developed a virtual mall to treat post-stroke patients. They used a relatively expensive system which requires video studio conditions (i.e. a green backdrop, lighting and large space).

Castelnuovo et al. (Castelnuovo et al., 2003) described the V-Store as a rehabilitation tool where patients with neurological damaged could be involved in several tasks with higher degree of complexity designed to stimulate the executive function, programming, categorical abstraction, short-term memory and attention. The authors provide no results of evaluation with patients. Lee et al. (Lee et al., 2003) designed a VS for the assessment and rehabilitation of daily-life activities. They mainly focused on the usability of the VE and tested it on patients with traumatic brain injury and stroke. A Eye tred^{TM} FMD-250Z head-mounted display, a Intertrax2^{TM} position sensor and a Airstik^{TM} 2000 joystick were used for observation, navigation and interaction.

Other studies were carried out using VS. For example, Carelli et al. (Carelli et al., 2008; Carelli et al., 2009) conducted a feasibility study of a shopping task developed using VR techniques. The task was to choose and buy products from a shopping list. The objective of the study was to investigate the usability of the system. Twenty healthy adults had to navigate in the VS using a handle (pushing right/left buttons) and select the items by pressing a button. Cardoso et al. have developed a VS to assess cognitive disability of patients with a left hemisphere stroke (Cardoso et al., 2006). The patients had to navigate within the VS and collect items using a mouse. Task was to complete a shopping list. Each time the patient selected a given item, a window appeared, asking him/her to choose the price which corresponded to the product. Klinger (Klinger et al., 2003; Klinger et al., 2006) and Marié et al. (Marié et al., 2003) designed the virtual action planning supermarket (VAP-S). The participants, seated in front of a 2D monitor, were instructed to explore the supermarket using a keyboard for navigation and a mouse for items collection (Josman et al., 2006; Josman et al., 2008).

2.2 3D Interaction Techniques

3D interaction techniques are the main components of VR systems. They have been classified as follows (Mine, 1995; Bowman, 1998; Bowman and Hodges, 1999): selection, manipulation, navigation and application control. During the two last decades several navigation techniques have been proposed and evaluated (Ruddle et al., 1997; Bowman et al., 1999; Usoh et al., 1999; Sutcliffe and Kaur, 1999; Vila et al., 2003; Suma et al., 2007; von Kapri et al., 2011; Bolte et al., 2011; Cirio et al., 2012).

Bowman et al. (Bowman et al., 1997) proposed a framework for the design and evaluation of navigation techniques for specific tasks in VEs. Later, Arns proposed extended Bowman's taxonomy and distinguished real translation/rotation and virtual ones (Arns, 2002). Results from experiments indicated that pointing techniques are advantageous relative to gaze-directed steering techniques. It was however observed that navigation techniques which instantly teleport users to new locations are correlated with increased user disorientation. Some generic hand directed motion techniques have also been proposed for navigation. The position and orientation of the hand determine the direction of motion through the VEs. These techniques appear efficient but tiring since the user has to constantly move his/her arms in space.

To be efficient, navigation techniques must allow the user to move easily within VEs while looking around. Therefore, researchers tried to develop intuitive interaction techniques for navigation and item selection. For exemple Renner et al. (Renner et al.,

2010) proposed a VS in which the user is able to navigate and look around at the same time using well-known interaction techniques based of body gestures. The authors used several methods like path drawing where subject use the Wii Remote^{TM} to navigate through the VE by drawing a path, the walking in place where they make step-in-place on a Wii Balance Board^{TM} to navigate in the VE. The authors also use non immersive interaction technique like world in miniature where users could see the VE like a map, and move from one point to another. More recent gaming input devices like the Nintendo Wii Remote^{TM} and the Nintendo Wii Balance Board^{TM} have been used for navigation and interaction with VEs (Fischer et al., 2011).

The most effective navigation techniques are based on real or real-like walking. Real-like walking techniques such as step-in-place have been developed and evaluated in a general context (Templeman et al., 1999; Bouguila et al., 2004; Richard et al., 2007). Beckhaus, Blom and Haringer (Beckhaus et al., 2005) present a navigation method based on the dance-pad, a physical device that has directional arrows activated by stepping. Real walking techniques have also been developed (Slater et al., 1995; Choi and Ricci, 1997) and proved to be very efficient (Suma et al., 2009). However, this approach either limits the users navigation space (Williams et al., 2007), or require some complex set-up such as cyberspheres (Fernandes et al., 2003), omnidirectional treadmills (Darken et al., 1997; Iwata, 1999; Suryajaya et al., 2010) or complex robotics system (Iwata et al., 2005).

3 EXPERIMENT

Our motivation to conduct this experiment relies on the need to get both objective and subjective data allowing to analyse user performance and preference for different interaction techniques in the context of shopping activities. The main objective is to identify the advantages, drawbacks and limits of the proposed interaction techniques.

3.1 Apparatus

The experiment was carried out using the VR platform illustrated in Figure 1. The platform is made of a back-projected screen (2m large x 2m high). The projector used for the experiment is an Optoma HD141X Full HD 3D 1080p Projector. The platform provides low-cost interaction devices such as the Microsoft Xbox^{TM} 360 ones : the game-pad controller and the Kinect^{TM} sensor. For real-time head tracking, we used a TrackIR^{TM} device.

Figure 1: Set-up used for the experiment.

3.2 Virtual Environment

The supermarket is of relatively limited size so that it can be explored in a relatively limited time. It consists of two shelves, a frozen food area, a bakery area, a magazine space, a cool space and two areas dedicated to fruits and vegetables (Figure 2). The 3D models were developed using 3DS Max. Then, they were exported in .fbx format and imported into the Unity3D game engine. The user can freely navigate inside the store and collect items. Once selected, the items are automatically put in the shopping cart that is placed in front of the user (Figure 3). Different disruptors (audible or visual) may be embedded in the simulation. Similarly, avatars can wander around the store and behave differently vis-à-vis the environment or the participants. The system records all movements and actions performed by the participants within the VE.

Figure 2: First-person view of the virtual shop.

3.3 Design and Procedure

Eighty volunteer students from our school of Engineers were recruited to participate in the study. They were split in four groups of twenty students each. Each group performed the task in a different condition (C_1, C_2, C_3, and C_4). Each subject was installed in front the visual display which was set in monoscopic viewing mode.

In condition C_1 (mean age : 19.0 ; SD : 1.41), illustrated in Figure 4 (a), the participants used the Xbox^{TM} 360 controller for travelling in the VE (left joystick), looking around (right joystick) and select items (green button).

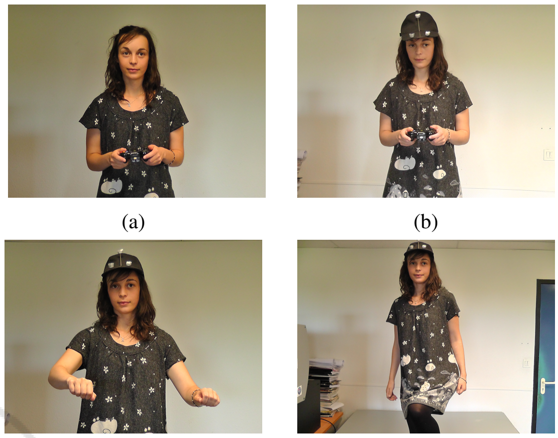
In condition C_2 (mean age : 19.04 ; SD : 1.78), illustrated in Figure 4 (b), the subjects used the left joystick of the Xbox^{TM} 360 controller for travelling, and a low-cost head tracking device (TrackIR^{TM}) for looking around.

In the condition C_3 (mean age : 22.05 ; SD : 2.25), illustrated in Figure 4 (c), the participants navigated in the VS using dynamic body gestures, similar to the ones used for operating a real shopping cart. Thus, to move the cart forwards, the users have to put both hands forwards. To move the cart backwards, they have to put both hands backwards. The navigation in the VS is based on hand movements, so to turn right or left, participants have to move up their hand in the chosen way. So to turn right, subjects have to place their right arm perpendicularly to their body.

Figure 3: Shopping cart containing some collected items.

As in the previous condition, the TrackIR^{TM} system was used for looking around. To collect the items, participants have to point on them and clap their hands. The Kinect^{TM} was used to capture participants arm movements. Motion data were processed using FAAST^{TM} (Flexible Action and Articulated Skeleton Toolkit).

In condition C_4 (mean age : 19.94 ; SD : 1.77), illustrated in Figure 4 (d), the users navigated in the VS using a step-in-place technique. To move forwards the subjects have to step-in-place in front of the visual display. Turning right or left was made using upper body's (shoulders) orientation.To collect items, participants had to point on them and clap their hands. As in the previous condition, the Kinect^{TM} sensor and FAAST^{TM} were used. The four conditions were chosen to be easy to use and based on low-cost devices.



(a) (b) (c) (d)

Figure 4: Interaction techniques : (a) using the game-pad only, (b) using the game-pad and the TrackIR^{TM}, (c) and (d) using the Kinect^{TM} and the TrackIR^{TM}.

3.3.1 Task

The task asked to the participants was to navigate inside the supermarket and collect the seven items from a list using one of the interaction techniques previously described. The list is positioned on the shopping card and is available to the subject during the completed task (Figure 3). User scan see the list in its integrity by changing his point of view. The purchased items are not delete when they are selected . Once the subject considered that all the items from the list were collected, they had to reach the cash register as quickly as possible. As the subject reached this area, the task was considered to be completed and the simulation ended. Each participant completed the task twice. At the end of the experiment, participants were asked to fill in the NASA TLX and the subjective questionnaires.

3.3.2 Collected Data

In order to compare the different interaction techniques, we collected performance data such as the task completion time and the travelled distance. We didn't observe any error. Users would made errors if they didn't respect the items of the list.

In addition, we used the NASA Task Load Index (NASA TLX) to assess the task's mental, physical and temporal demand, the user's perceived performance, effort and frustration. A non standardized usability questionnaire was used to assess participants' habits in playing video games and to evaluate on a seven Likert scale their enjoyment during the task and overall system usability. We also observed the subjects while performing the task and noted their comments, strategies and behaviour.

3.4 Results

The R statistical software was used to analyse the data, at a significance level of 0.05. Kruskall-Wallis test was used to compare the four conditions C_1, C_2, C_3 and C_4 using performance data (time, errors and distance travelled) and using the data collected via the questionnaires. Post-hoc analyses, conducted with a Mann-Withney test for independent samples, were used to compare the different conditions and a Cliff Delta was conducted to measure size effect. A modified T-test (Crawford and Howell, 1998) was conducted to compare an individual score against the norm. It was used in the context of comparing individuals with no experiences in video games to the the rest of participants of her/his group with habits in video games.

The results are presented in the following order. First, we look at the task completion time associated with each condition. Then, we report about the distance travelled by the subjects while performing the task. Finally, the data collected using the questionnaires (NASA TLX and usability) are presented.

The results revealed that no subject has made mistakes during the task and have collected all the items of the list. Comparisons between trials 1 and 2 was made with a U Mann-Whitney test. For all conditions, trial 2 was better than trial 1 in terms of completion time, numbers of errors and distance travelled. In this section, we present the data for the second trial only.

3.4.1 Completion Time

Results are illustrated in Figure 5. To complete the task, users needed significantly less time in C_2 condition (game-pad + head tracking) than in C_1 condition (game-pad only) ($U = 124$; $p = 0.04^*$)($\Delta = -0.38$), C_3 (arms movement + head tracking) ($U = 46.5$; $p = 0.00005^{***}$) ($\Delta = -0.75$) and C_4 (step in place + head tracking) ($U = 16.5$; $p = 0.000001^{***}$)($\Delta = -0.91$). There is no significant different between C_3 and C_4, conditions ($U = 137$; $p = 0.21$).

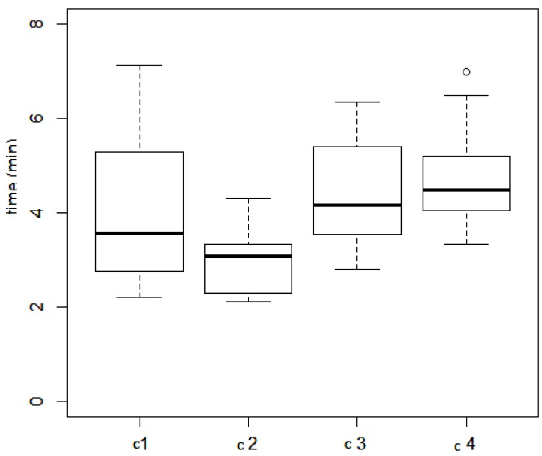


Figure 5: Time to complete the task (second trial) in the four conditions.

3.4.2 Distance Travelled

Results are illustrated in Figure 6. They showed that in C_2 condition (game-pad + head tracking) participants travelled significant shorter distances than those in C_1 ($U = 128.5$; $p = 0.05^*$)($\Delta = -0.35$), C_3 ($U = 622$; $p = 0.0003^{***}$) ($\Delta = -0.67$) and C_4 conditions ($U = 58$; $p = 0.0002^{***}$)($\Delta = -0.69$).

3.4.3 Effect of Skill

A modified T-test was realized to analyse the performance of players with bad skills in video games. Some of them needed significantly more time to complete the task. Indeed, the analysis shows that several subjects with bad skills in video games had poor time's performance. In C_2 (game-pad + head tracking), one participant presents bad skills in video games and took significantly more time to complete the task ($t = 2.14$). In C_3 (arms movement + head tracking), seven participants were unfamiliar with video games and only one took significantly more time to complete the task ($t = 1.9$). In the first condition with game-pad, over seven participants, one took significantly more time to complete the task ($t = 2.1$), and another made a significantly longer path ($t = 2.09$).

In the two conditions C_1 and C_3, there were seven users with bad skills in video games, so these conditions were divided in two groups: one with users who have good skills in video games and the other with participants who have a strong experience of video games.

In the game-pad conditions, the group with bad skills in video games made significantly longer paths ($U = 17$; $p= 0.02^*$)($\Delta = -0.62$) and needed signifi-

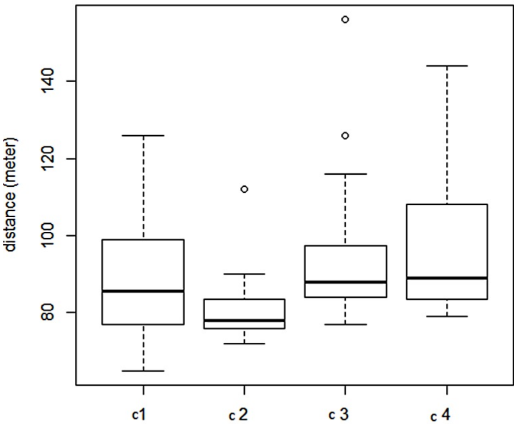


Figure 6: Distance travelled (second trial) in the four conditions.

cantly more time to complete the task (U = 5.5 ; p = 0.01*) (Δ = -0.88). However, in the Kinect^{TM} conditions, there was no significant difference between the group with good skills and the group with bad skills, in term of travelled distance (U =53; p =0.53) and completion time (U = 34 ; p= 0.39).

3.4.4 Subjective Data

We observed that two scales of the NASA TLX were significantly different : effort and frustration. Participants from the C_2 condition (game-pad + head tracking) produced less effort than those from the C_3 condition (arms movement + head tracking) (U= 101 ; p= 0.01*)(Δ = -0.46) , and less effort than those from the C_4 condition (step-in-place + head tracking)(U= 89 ; p= 0.004**)(Δ = -0.53). Results of the frustration scale indicated that the participants from the C_2 condition felt less frustration than those from the C_3 condition (U= 11.6 ; p= 0.04*) (Δ = -0.38) and those from the C_4 condition (U= 66.5 ; p= 0.0005***) (Δ = -0.65). Participants from the C_4 condition also felt more frustration than those from the C_1 condition (U = 261 ; p = 0.02) (Δ = 0.44).

Participants were asked to complete a questionnaire about easiness of the interaction technique and the task's enjoyment. The Kruskal-Wallis test indicated no difference between the four navigation techniques (p=0.08). Participants from the C_1 condition found the task less funny than those from the C_3 condition (U = 286.5, p=0.02*) (Δ = 0.36) and those from the C_4 condition (U=250 ; p = 0.04*)(Δ= 0.31). Similarly, participants from the C_2 condition found the task less funny than those from the C_3 condition (U = 128.5 ; p = 0.02*) (Δ = -0.38) and from the C_4 condition (U= 121.5 ; p = 0.03*) (Δ = -0.36).

4 DISCUSSION

We developed a virtual supermarket for the assessment and rehabilitation of patients with cognitive impairments. In order to get both performance and subjective control data, we carried out a user study with volunteer students. The goal was to compare navigation and selection techniques ranging from desktop interaction techniques using a game-pad to full body gestures. Navigating and collecting items using full body gestures seem a-priori more intuitive and natural, especially for the step-in-place technique (C_4 condition). However, desk-top devices such as the game-pad are easy-to-use (Vera et al., 2007) and most people who play video games know how to use it very well. We observed, that no matter the interaction techniques, in all conditions, participants were significantly more efficient in performing the task after one trial. They all travelled shorter distances in the supermarket and spent less time to complete the task. Thus, the proposed interaction techniques and the task are easy-to-learn.

Interaction techniques based on the Kinect^{TM} was proposed for people unfamiliar with video games because of their easiness (Roupé et al., 2014). Indeed, full body gestures are more suited for people with no skills in video games. According to a previous study (Roupé et al., 2014), results show that the participants with no skills in video games could perform the shopping task as well as participants with good skills in video games. However for the game-pad conditions, participants with no skills in video games got lower performance, and needed more time to perform the task.

Previous studies present various results. Consistent with our results, Teixeira et al. (Teixeira et al., 2012) showed that the game-pad was more effective than a step-in-place navigation technique (Teixeira et al., 2012; Figueiredo et al., 2014). However in Renner et al. (Renner et al., 2010), the step-in-place condition was the most effective for navigating in a virtual shop. In another VE, the walking-in-place condition was better than a joystick condition (Riecke et al., 2010). In this study, users worn an HMD and had to find some hidden items in a VS. The poor performance with the joystick may be due to the lack of visual exploration of the VE (Riecke et al., 2010).

Results of the NASA TLX indicated that participants produced more effort in the Kinect^{TM} conditions than in the game-pad conditions. This is not surprising since the participants have to move their arms (condition C_3) or their whole body (condition C_4) to control the shopping cart and collect items. Results also revealed that in these conditions, the participants felt some frustration because of the difficulty to control the cart (DSouza, 2011). Thus, such interaction techniques do not appear to be the most effective ones, especially for the elderly people or people with motor impairments, however participants found them more enjoyable than those with game-pad. In addition, producing efforts to navigate and interact with VEs may increase user's sensation of immersion (Herrewijn et al., 2013).

Time and distance travelled in a VE appear to be the good data to assess users performance and the usability of interaction techniques. Indeed, interaction techniques are considered effective when the user can build up a cognitive map with the acquisition of spatial knowledge (Bowman and Wingrave, 2001). In this context game-pad devices are the most effective but need several trials to be used with optimum abilities, whereas full body gestures interaction techniques based on motion capture devices such as the Kinect^{TM} are more easy to use for people unfamiliar in video games. In addition, navigating using body gestures made the task more enjoyable for the users.

Change the interaction techniques may be interesting according the task or the difficulties encountered by the patient. For example, according the mood of the patient, we may simplify the interaction technique. Indeed, rehabilitation training could be long and repetitive, so the interaction technique with Kinect^{TM} may permit to raise the patients motivation when he/she is fed up with doing the same task again. On another side, if the patient wants to see his progress, an interaction technique based on game-pad may be effective.

5 CONCLUSION AND PERSPECTIVE

In the paper, we have presented a VE that simulates an everyday task to assess cognitive impairments: going shopping at the supermarket. A user study has been carried out to collect baseline control data using volunteer students from our school of engineers. The task was to collect various items within the supermarket using a shopping cart. Four different interaction techniques have been compared ranging from the desktop paradigm to natural interaction techniques based on full-body gestures. We observed that subjects were more efficient in terms of completion time using a game-pad but enjoyed more the interaction techniques based on full-body gestures. However, the NASA TLX questionnaire revealed that these interaction techniques led to more fatigue and frustration. As future work, we plan to evaluate users sensation of presence associated with the different proposed interaction techniques using questionnaires and physiological responses.

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