Development of an Immersive VR Simulator Using the Unreal Development Kit

Vitor A. M. Jorge*, Augusto Hoppe*, Anderson Maciel*, Luciana Nedel*, Gelson Reinaldo‡, Frederico Faria‡, Jackson Oliveira† and Pedro Montani†

*Instituto de Informática - UFRGS, Porto Alegre, RS Emails: {vamjorge,augustohoppe,amaciel,nedel}@inf.ufrgs.br

†AES Sul, Porto Alegre, RS. email: {jackson.oliveira, pedro.montani}@aes.com

‡Nexo.Art.Br, Porto Alegre, RS. email: {frederico,gelson}@nexo.com.br

§Urizen Technology, Caxias do Sul, RS. email: gelson@urizen.com.br

***Abstract*—This paper discusses the challenges in the development of a Virtual Reality simulator to train and to assess the risk perception among maintenance technicians using the UDK game engine. The project involves a multidisciplinary team from different areas and the design of transparent 3D user interfaces. Such simulator can be a great tool to reduce accidents and costs, since accidents in power distribution operations are frequently caused by behavioral deviations. We present the initial experiments, showing a positive reaction from the users when they see their own limbs. The results indicate that the system provides a reasonable feeling of presence, already at the current stage of development.**

***Keywords*-User Interfaces; Virtual Reality; Risk Perception**

I. INTRODUCTION

Power generation, transmission and distribution companies have made huge investments along the years to train personnel and to develop safe equipment. It considerably reduced the accidents and the gravity of injuries. However, a large amount of accidents in the daily activities of a distribution company happen due to behavior deviations, i.e., human factors can put the professional at risk. That is, one's perceptions and actions towards dangerous situations are affected by social factors, the working environment, leadership, group influence, etc. For instance, a working environment without mutual trust can put the professional under stress, making him overly cautious or too nervous to safely execute the job.

While physical training sites and other strategies exist, they cannot often reproduce certain conditions without putting the professional at risk. Besides, due to the unfeasible amount of time and resources required, they do not allow a range of variations of the same procedure to be done frequently. These strategies are not portable and sometimes not effective due to the lack of realism provided. Furthermore, they require the presence of psychologists and other experts, since there is no established way to detect behavior deviations during the task execution.

This paper is part of a project, whose long term goal is to simulate dangers and to assess and improve the risk perception among workers of AES Sul[1] through an immersive Virtual Reality (VR) simulator. The expected result is to improve safety conditions and minimize the accidents in the company.

In this short paper we describe the ongoing development of such simulator for selected operational procedures. As the design of immersive simulators is a complex task, we propose a solution integrating 3D interaction devices and techniques with a game engine, the Unreal® Development Kit (UDK). While our main contribution is in how to benefit from a game engine in a serious application, we also present a preliminary system evaluation. We have evaluated a hand/arm-based locomotion technique. Even though the technique is not based on the more natural feet movement, preliminary results show that the user presence in the Virtual Environment (VE) is maintained.

II. RELATED WORK

The use of VR applied to the power industry is not new. Bingda et al. [2] developed a Web based non-immersive VR system to simulate substation operation and maintenance. It provides eight individual types of faults that can be combined into complex ones. They observed that the training should not use fixed layouts, since a diverse training can turn trainees into more versatile specialists. VR fits as a solution because it can generate new layouts at zero cost. Sebok et al. [6] argue that invisible substances, such as radiation or gas, can be made visible. They state that there is knowledge transfer from the virtual to the real environment and show that VR enhances the learning experience. Recently, Rosendo et al. [5] developed an innovative system to train live line maintenance staff using VR through a large-display paradigm and Wiimotes. These systems are focused on training, rather than evaluation.

Asnar and Zannone [1] introduced the concept of perceived risk, and highlighted some other important concepts such as: trust, i.e. the confidence you have that a person will act as expected; and risk tolerance, how much one can

[1]AES Sul is a large power distribution company

afford to lose by taking a risky attitude. They understand that the perception of risk is relative to every user according to his/her inner motivations and their relations with the other users. In other words, every person weighs the trade-off between acting safely or choosing a risky behavior.

Game engines have already been used for VR applications. They were used to train medical staff for battlefield simulations of life saver procedures [4] using visual cues to facilitate the understanding of the conditions of the injured soldiers in the VE. Kavakli et. al [3] developed a simulator to train police officers on crime risk assessment. They integrate the traditional training scenarios with natural language processing and a desktop VR core. However, those systems made use of desktop metaphors, avoiding the challenges imposed by fully-immersive environments.

III. Project Overview

A long term goal is to detect and minimize risky behaviors, which requires not only the design of an immersive VR training system, but also a deep analysis of human factors. Thus, the project involves a multidisciplinary team of subject-matter experts in the core process, human factors, computer science, human-computer interaction and evaluation.

It covers four modules, as presented below. The **administrative area** module, comprising the offices of the company and its domestic dangers. The **substation operation/maintenance** setup, including a number of procedures to be carried out in the station. The **lightning-rod replacement**, involving live line maintenance and the dangers of deadly currents. And finally, **reading and delivering a consumer invoice**, when the technician should enters the consumer facilities to read the power meter. In these procedures, the careful execution of all steps described in the manual avoids most of the expected accidents. However, human factors might lead the professional to disrespect one or more safety steps.

The team lists the possible dangers in each work environment, where each danger is associated to its own risk. Risks are classified into light, medium or serious. This matrix of competencies also associates the possible decisions a person can make when exposed to each possible risk.

We are currently in the development of the first module of the project, assessing the administrative area challenges. At this stage, we have found a number of solutions to integrate VR equipment and techniques with a game engine. The next section details the choices we made and the system architecture we came up with.

IV. System Implementation

In this section, we present the design and implementation of the system, showing how we control the complexity presented by the development of an immersive environment.

A. Project Assumptions

We are interested in a system which is **fully-immersive**, **portable** and **simple to integrate**. With these assumptions, we chose devices and programming environments that could provide such characteristics while minimizing the need for development resources. Additionally, the procedures for live line maintenance at *AES* always involve more than a single person, for safety reasons. Thus, the design is challenging, since it must support more than one user at a time.

Although computer games are not strictly speaking fully immersive, they are by definition perceptual and interactive. Game engines then provide many features to simplify the development of VEs. Besides, in the industry there is often a goal that must be achieved by the working personnel, which can be easily translated to computer game goals. Also, the computer graphics required to create several visual effects such as rain, shading, a variety of sounds, etc. are easily deployed using an average game engine. When compared to 3D graphical engines, game engines have the advantage that they map several events that are not always available in the graphical engines in a very clean way. These events provide a way to create simple games with predefined goals very fast.

We have chosen UDK for many reasons. It grabs keyboard and mouse inputs in a transparent way which most game players are used to do. It does not provide full access to the programming environment in the open-source license, but with this license we can access and modify most of the development features, including collisions, player position, camera, etc. through scripts. The addition of NIUI (OpenNI® Unreal Implementation) and Kinect to the UDK, allows the creation of fully immersive environments where the users can see and move their own limbs. It also makes the system portable and clean to implement.

We are interested in the risk perception, so the user interface must be as natural as possible. Furthermore, all the procedures contemplated by the system involve the use of bimanual actions. Thus, we have opted to use hands and fingers to collect user perception information. We have chosen the 5DT® data glove because it maps gestures to keyboard strokes, which are easily interpreted by UDK to provide point, grab and move gestures. The combination of the data gloves with Kinect is fundamental, since it provides the hand as well as the finger joints positions, enabling bimanual activities in the VE.

The HMD was chosen over the CAVE and derived strategies as we require a portable system. The HMD also maps the head movement to mouse coordinates, leading to a seamless integration with the UDK.

B. System Architecture

We have designed an architecture that is simple to implement and integrate. Fig. 1 shows that the integration is handled in a seamless way by the operating system.

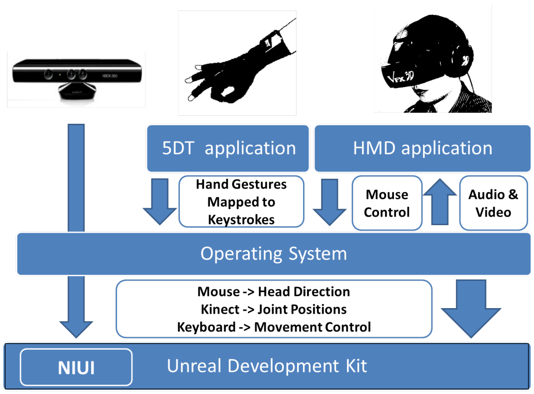

Figure 1. The system architecture. Note that most of the integration is handled by the operating system and the UDK in a seamless way.

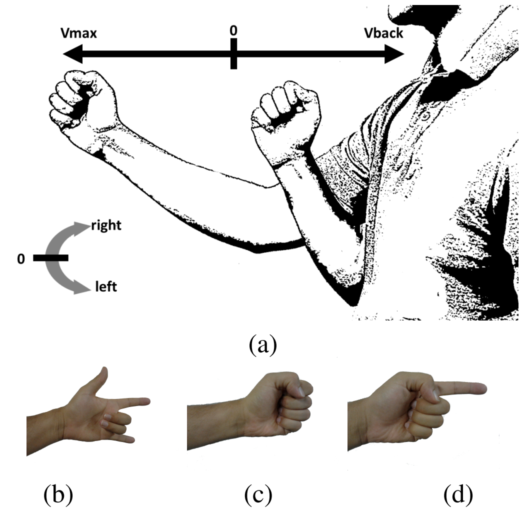

Figure 2. Fig. (a) illustrates the locomotion strategy. When the arm is fully extended, the user moves forward at maximum speed ($Vmax$). As the arm is flexed towards the preset rest position, 0, in the horizontal bar, the speed gradually decreases. However, if the arm is flexed below 0, the movement is in the backward direction ($Vback$). The walking direction is controlled moving the arm to the left or right of the preset position 0, in the gray arrow. To avoid unwanted movements, we restrict the navigation to a combination of arm movements and a hand gesture. Figs. (b)-(d) show the gestures used for locomotion, grabbing, and pointing objects respectively.

The gesture interpretation is done using a program that runs in parallel to the UDK, converting gestures into keystrokes. In the same way, the HMD head-tracking is used to move the mouse pointer. Thus, the UDK only sees the keystrokes and mouse pointer positions given by the operating system, even though they were generated by non-conventional interaction devices. The position of the joints is provided by Kinect. The NIUI and UDK map the actual joint positions to the avatar joint positions. This way, the user sees their own virtual limbs, providing additional immersion and presence.

In most of the procedures, the navigation in the VE is a secondary activity. Thus, we have decided to implement a known navigation strategy that does not impair the felling of presence. It uses both, Kinect and data gloves. The arm position controls the movement velocity module and direction, while a data glove is used to trigger the movement. This strategy is explained in detail in Fig. 2.

In order to provide pointing, grabbing and locomotion control we have used three basic gestures (Fig. 2 (b)-(d)). In all these gestures, the thumb position is irrelevant. The chosen walking gesture was set when both the index and little fingers are extended and the middle and ring fingers flexed (Fig. 2 (b)); the grab gesture is set when all the fingers are flexed (Fig. 2 (c)); and the pointing gesture was set when only the index finger is extended (Fig. 2 (d)). The pointing gesture is only achieved if the object is within the eyesight, information which is provided by UDK.

V. Results

We performed initial system experiments with the impact of the selected navigation strategy on focus and feeling of presence. We selected four users experienced with video games and, with some experience with VE and the VR devices in use. We asked them to find the printers in the work environment and placed some objects on the floor to check if they were able to notice them even when they are using such unnatural locomotion strategy. Then, we asked if they had noticed something dangerous during the task. For training purposes, the users were asked to practice as much as they wanted to and, when comfortable, to proceed to the given tasks in the virtual office. We recorded the path taken and the time required to complete the task, excluding the training time.

The last experiment involved the observation of user reactions in the event of an unexpected explosion. It consisted of a particles effect and a loud explosion sound, followed by the sound of a groaning person. The event always occurred when the user had reached one of the printers. Two seconds later, the experiment was ended. This was done to see how the user reacts to the VE dangers, presented in the form of visual and sound cues, in a similar way they would normally do in a real situation.

The navigation strategy did not induce disorientation to any user. Users found the velocity of movement too slow. They completed the task in $103.91s$ on average. The movement did not present any aberrations (see Fig. 3). The thick yellow lines represent sidewalks, while the blue lines represent the user path. Moreover, when they were asked if they had difficulty to move inside the VE, they were divided. This can be easily explained by the movement forward, which required the right arm to be straight during a relative long period of time. Not surprisingly, the users with less arm strength complained the most, while the others did not find it so difficult. This is a known problem of gesture based

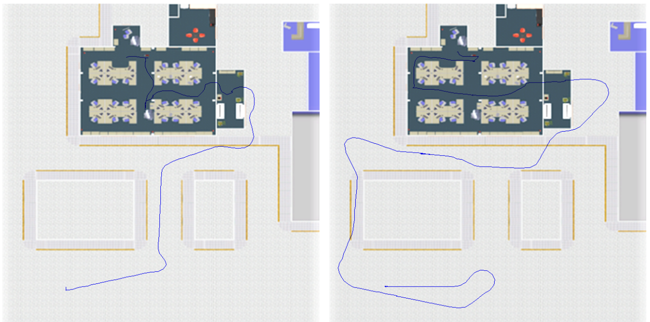

Figure 3. Path used by two test subjects in the administrative environment.

Figure 4. The proposed system. The Figs. show the user movements (left), and the corresponding system response (right).

movement.

All the users were surprised with the explosion and seemed really scared. They associated the event with a wrong behavior. This is useful since in live line maintenance, the worker cannot make mistakes. A VE where the errors are clearly marked, almost shocking the user, can be very useful to correct risk behavior.

A usability questionnaire showed that most users were focused/absorbed by the task. The HMD was considered natural to most users, perhaps with a small adjustment to decrease camera rotation speed. Most of them noticed the object on the floor, but one did not see any potential risk of a fire extinguisher dropped in the middle of the office corridor.

VI. Conclusion and Future Work

We have shown the development of a serious game simulator for risk perception, presenting an overview of the system architecture and implementation details. Our guidelines were: simplicity, effective full immersion, and portability. The system basically uses commodity devices and software, such as the UDK engine, NIUI+Kinect and the data gloves. They have presented a seamless integration into a consistent and easy to implement system, since most of the integration is handled by the operating system.

Most users liked the system and reported to be immersed during the task. However, the locomotion strategy caused a disruption between leg joints and actual movement. It results in an unpleasant sensation of sliding legs.

We are now extending the system to accept more scenarios, including various mini-games required to complete a complex task. We plan to include features, such as the support for more than one user, the use of a more natural locomotion strategy, stereoscopic vision, bots with predefined behavior created to induce wrong risk behavior, full finger joint movement representation, exploring ways to improve the precision of the limb joints position, etc.

VII. Acknowledgements

Thanks are due to AES Sul Distribuidora Gaúcha de Energia for funding and for the valuable expert support, Nexo Comunicação e Capacitação Digital (www.nexo.art.br) for the 3D modeling and CNPq-Brazil for the complementary support to the UFRGS researchers under the projects 311547/2011-7, and 302679/2009-0. Thanks are also due to Aline Carlos from AES Sul, Diego Madia and Raphael Costa from Nexo, Julio Turbay from Comportamento and Fausto Araújo from Urizen Technology for their participation in the project.

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