



Creating a collaborative system for physical protection simulation in nuclear facility with virtual

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Abstract: In recent years, the importance of improving physical protection in nuclear facilities has been observed, mainly due to the increasing progress of the Brazilian nuclear program. Physical protection requires great attention and strategies that must be designed, tested and improved in order to maintain the physical integrity of the facilities and population. These strategies should be tested in exercises to see if the physical protection plan - PPP is in accordance with the actual conditions of the facility, such as: visibility of the borders and terrain, number and equipment of the team in charge of defense (security guards), detection equipment and access times of central security point agents to the places where suspicious activities have been detected. In this sense, this article aimed to develop a tool that allow the visualization and planning of action strategies in a virtual environment, aiming to improve security. A virtual model of the Instituto de Engenharia Nuclear (IEN) was created, with close representations of reality and the virtual characters can transit and interact in real time. Various situations that affect the visibility and detection of opponents, such as natural and artificial lighting, climatic phenomena, shadows and others can be simulated with a high degree of realism. In addition, the tool has a surveillance system through virtual cameras, enabling monitoring of the environment. Thus, this system will allow to simulate approach strategies, allowing an evaluation of the procedures performed, as well as assist in physical protection training in radioactive and nuclear facilities.

Keywords: Virtual Reality, Physical Security, Collaborative System.



O uso da realidade virtual no desenvolvimento de um sistema colaborativo para simulação de segurança física em instalações nucleares

Resumo: Nos últimos anos observa-se a importância de aprimorar a segurança física em instalações nucleares, principalmente devido ao crescente avanço do programa nuclear brasileiro. A segurança física nuclear requer grande atenção e estratégias que devem ser elaboradas, testadas e aprimoradas de forma a manter a integridade física das instalações e da população. Estas estratégias deverão ser testadas em exercícios para saber se o plano de proteção física está de acordo com as condições reais da instalação, tais como: visibilidade das fronteiras e do terreno, número e aparelhamento da equipe encarregada da defesa (agentes de segurança), equipamentos de detecção e tempos de acesso dos agentes do ponto central de segurança aos locais onde tenham sido detectadas atividades suspeitas. Nesse sentido, o presente artigo teve como objetivo desenvolver uma ferramenta que permitisse a visualização e o planejamento de estratégias de ação em um ambiente virtual, visando melhorar a segurança. Para tal, foi criado um modelo virtual do Instituto de Engenharia Nuclear (IEN), com representações próximas da realidade, onde os personagens virtuais podem transitar e interagir em tempo real. Situações diversas que afetam a visibilidade e detecção de adversários, como iluminação natural e artificial, fenômenos climáticos, sombras e outros podem ser simulados com alto grau de realismo. Além disso, a ferramenta possui um sistema de vigilância através de câmeras virtuais, possibilitando o monitoramento do ambiente. Deste modo, esse sistema possibilitará simular estratégias de abordagem, permitindo uma avaliação dos procedimentos efetuados, bem como auxiliar no treinamento de segurança em instalações radioativas e nucleares.

Palavras-chave: Realidade Virtual, Segurança Física, Sistema Colaborativo.

1. INTRODUCTION

With the growth and expansion of Brazilian nuclear power plants [1], physical and nuclear safety should be one of the most carefully thought strategies. Each institution shall consider all hazards that may occur on its premises. To maintain the integrity of the entire population and facilities themselves, nuclear security strategies must be developed, tested and improved.

In the broadest sense, the term Nuclear Security refers to a series of measures implemented by States and International Organizations to ensure safety in the handling, use and storage of radioactive materials [2]. International agencies such as the International Atomic Energy Agency (IAEA) work together with signatory countries to develop standards and procedures to prevent accidents from happening if they occur and to prevent access to radioactive materials by states or individuals with suspicious or questioned intentions. The responsibility to apply these standards and procedures lies with the State, but given the consequences of a nuclear attack, a framework of international legal instruments allows for joint work between States to ensure security in transnational terms [3]. In light of terrorist attacks in several countries, the international community recognizes that new and more powerful measures must be taken to protect and prepare for a range of attack scenarios that include nuclear terrorism [4].

The safety of a nuclear facility should be the focus of great attention and safety strategies should be elaborated, tested, and improved to ensure that these materials remain stored and accounted for and that they are not at risk of falling into the possession of opponents [5]. In the development of a security strategy many factors must be considered, and the task is complex. Initially, it is necessary to define what one wishes to protect, what degree of protection each part of the facility should have and who or what to protect, that is, estimate the possible adversaries and their capabilities [6]. This strategy should be tested

in real exercises to see if there is an adequacy of the defense plan with the actual conditions of the facility, such as: topology of the site, visibility of the borders and terrain, number and equipment of the team (security guards), detection equipment and access time of central security guards to the places where suspicious activities have been detected [6]. The process of developing a security strategy therefore requires time, financial resources and the involvement of the team that elaborates the strategy, the one that executes it, from the direction of the facility and even from external services to the facility, such as police, fire department and hospitals.

Meeting these needs, the use of Virtual Reality (VR) allows recreating close representations of reality for an individual, enabling a real-time interaction. Virtual Reality, also known as VR, is an interface technique that aims to improve the interaction between man and a system to achieve a greater sense of immersion of the user in virtual environments. One of the main keys to VR is the virtual world's response to user interactions through gestures, voice, among other stimuli that further praise the sense of immersion that this type of technology offers [7]. This technology can be applied in the most diverse areas, such as training, simulations, virtual experiments, and every day new jobs are discovered this technology [8]. These VR environments provide some advantages, such as: (i) being attractive to the user, because they allow them to feel immersed in the respective environments, without being exposed to any risk; (ii) allow simulations and evaluations of facilities not yet built in the real world, or which may be difficult to access; (iii) contribute to better planning of activities in the area of nuclear safety, and consequently assessing risks.

In recent years, Virtual Reality technologies have been used in several areas of knowledge for training and simulation:

- Evaluation and mapping [9] of dose in a virtual reactor room, with online feeding of dose levels of a real reactor;

- Simulators of facility, configuration and use of safety equipment [10], including surveillance cameras and radiation detection equipment;
- Simulators for studies and training of evacuation of work and industrial environments [11, 12], operated by multiple users (each user represented by an avatar) and with the presence of autonomous characters;
- Training and evaluation of the physical and tactical defenses of a nuclear facility [13];
- Study of technological and cognitive assumptions for the improvement of virtual laboratories and virtual collaborative environments for radiopharmacy [14].

Virtual Reality technology is already applied in the areas of engineering, architecture, medicine, among others. Conjecture about how this technology can be even more useful, stimulating the production of simulators is shown to be a solution, especially for areas where training in a real environment would be considered costly and potentially dangerous.

In this work, general characteristics of virtual laboratories and collaborative environments were analyzed, both in their technological aspects and with reference to the cognitive profile of the professionals who use them. In this context, this work proposes present the construction of a computational model using virtual reality techniques that represents a real facility in the highest possible level of detail, so that in this computational model it is possible to carry out tests of physical security strategies.

2. MATERIALS AND METHODS

2.1. Virtual Reality

The Virtual Reality recreate as much as possible the sense of reality for an individual, leading him to adopt this interaction as one of his time realities. For this, the interaction is

performed in real time, with the use of techniques and computational equipment that help in the expansion of the user's sense of presence [15].

2.2. Modeling Tools

Three-dimensional modeling consists of the process of developing computational graphic representation of surfaces or three-dimensional objects. These produced models can be static or animated and can be developed in various specialized software. Such software is commonly called modeling tools.

Autodesk 3Ds Max is a modeling tool that aims to be a complete solution not only in modeling but also in the rendering, animation and simulations in three dimensions, thus meeting the needs of various computer graphics professionals in the development of various applications, such as games, virtual models, cinema, animations and etc. [16]. With great acceptance in the current computer graphics market, 3ds Max is one of the main proprietary tools for three-dimensional modeling. Its three-dimensional modeling and texturing capabilities provide great flexibility in the construction of meshes and surfaces, mainly due to its characteristic support for vector maps and the possibility of creating parametric objects. Through these features it is possible to assign and edit the textures applied to the models, as well as apply shading to creations [17]. 3Ds Max was used to model in three dimensions the external structure of the buildings at Instituto de Engenharia Nuclear (IEN), following their respective real measurements (height, width and length).

2.3. Game Engines

Game Engines, also known as game cores, are programs intended to produce video games. To this end, these programs centralize various libraries and functions needed for development, providing the programmer with quick access to the tools required to create these games. Basically, such software provides the fundamental capabilities for creating a game, especially a real-time graphics rendering core, accompanied by collision detection

functions and a physics core, and can also provide several additional features. Game cores can also be adapted and used for the development of other applications that require real-time graphics [18].

To provide the game developer with a complete and agile environment, the most widely used game engines are accompanied, by default, with integrated tools for creating and editing content, such as scenario editors and script interpreters for programming functions necessary for games and applications. In addition to these, to characterize itself as a core of games the tool must provide some fundamental features, such as audio playback, animation support, video playback, communication skills with other instances of the application for network communication (multiplayer applications), artificial intelligence functions, access and interpretation of files, memory management and etc.

Unity 3D consists of a robust three-dimensional game core, complemented by several functions needed for game development, such as libraries designed to insert physics into environments, lighting, and interactive audio. Unity uses Direct3D, OpenGL, OpenGL ES and some proprietary APIs to render its objects. Its rendering supports relief mapping, reflection and parallax, dynamic shadow processing, and post-processing effects. An important feature of rendering in Unity 3D is the use of the Occlusion Culling Method, with which only objects that are visible in the scene are rendered in real time. Leaving all other components of the environment, which are out of the camera's reach, out of processing. This avoids performing unnecessary calculations, optimizing the process, and improving the performance of the game [19].

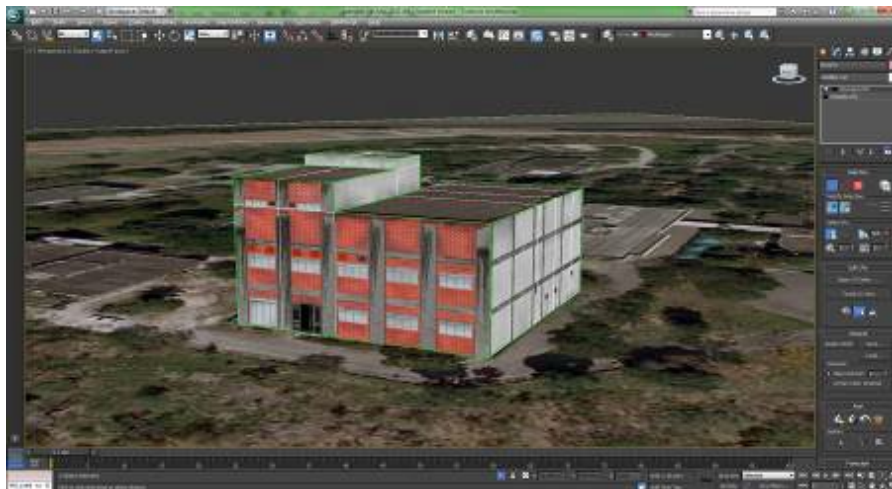
The method for developing the virtual simulator proposed in this article was divided in two stages. The first was terrain modeling and buildings using Unity 3D tools (land creation) and Autodesk 3Ds Max software (object and building creation). The second was deployed the functionality in Unity, such as: the movement of the avatar, the multi-user system, the weather, and climate system, and implemented the virtual camera center.

2.4. Building Modeling

The modeling of the terrain and buildings were developed using the software Autodesk 3Ds Max. Only the exterior of the buildings were modeled. The technique Poly Modelling was used. It consists of adding a primitive box to the virtual space and then, through the tools offered by the software, the shape was sculpted until the stage in which the virtual model transmitted the credibility of being a representation of reality.

After the construction of the buildings, the texturing process was carried out. The object had its mesh flattened and later transformed in figures, being later applied the three-dimensional model tools. Figure 1 shows the flattened texture applied to the model, and each of the textured faces coincident with the real building that is positioned in the virtual space.

Figure 1: Textured buildings in 3ds Max.



Source: Authors.

2.5. Terrain Modeling

The terrain modeling was performed with the Unity 3D game core. Using the measurements and proportions derived from the topographic image of the nuclear facility, regarding the extents and scales of the scenario, the standard terrain of Unity 3D was scaled. The shapes, width and length of the land under development were appropriate to the actual ones found at the nuclear facility. After adjusting the virtual terrain in relation to the shapes

and scales of the real environment, the same topographic image used for reference as a texture of this terrain was applied. With the proportions already equivalent, this texture, still flattened, adjusted correctly to the modeled environment, allowing the visualization of the points necessary to insert the exact locations where the buildings should be positioned.

With the virtual terrain already developed, the insertions of existing objects and buildings in the real environment were initiated. The 3D objects produced in Autodesk 3Ds Max were imported into the Unity 3D terrain. These elements were positioned according to the true layout of the site buildings, and received escalation within the core of the game, to respect the existing proportions. To provide greater realism to the virtual scenario, the vegetation characteristics found in the facility were also inserted, such as grasses, shrubs, and trees, as showed in Figure 2.

Figure 2: Three-dimensional models inserted in Unity.



Source: Authors.

2.6. Virtual Environment Avatar

To provide greater realism to the proposed system, changes were made to the characteristics of the avatars in the virtual environment. First, the visual characteristics of these characters were altered, providing the user with a visual identification with characters similar to those commonly found in the nuclear facility, as showed in Figure 3. In addition

to clothing and expressions, the height of the avatars was changed to 1 m and 70 cm, according to the average height of an adult man [13], and the displacement speeds of the character were adjusted to reflect the true speed of displacement of a human being within the nuclear facility.

Figure 3: Avatar developed for simulation.



Source: Authors.

Measurements were taken of the average speeds of people walking and running within the site, and these measurements were applied to the avatars. The height of possible jumps that individuals could perform within the environment was also measured, with these parameters being applied to the virtual characters.

2.7. Multi-user system

The virtual environment can be operated by one or multiple users. When start the program, a menu is displayed for the user to define which version. In "One User" mode only one person can use the program, thus controlling a simulation avatar. While in "Multi-user" mode, a group of people can interact together in the same scenario, being able to interact with objects or other virtual characters.

2.8. Weather and Climate System

To enable simulations with different climatic conditions at the most different time of the day, a system was developed to control weather and climate in the virtual environment. Figure 4 shows an image of the weather and climate system. This feature allows the application in the setting of all natural features over the hours, such as lighting, shadows, positioning of the sun, appearance of stars, lunar phases, and others.

Figure 4: Weather and Climate System. (a) Virtual environment during the day, with the positioning of the sun affecting the shadows of objects. (b) Virtual environment at night, containing a system of lunar phases and stars.



Source: Authors.

A control menu was also implemented to management the meteorological characteristics of the virtual environment. These conditions allow the user to change between different scenarios such as rain, fog, among others. Through this list of options, the user can determine the weather and climate conditions in their proposed scenario, as well as choose the time of day through a scroll bar available in the application. Weather features can also be chosen from several options available, such as: cloudy, sunny, rain, storm and etc. In order to increase the realism of the virtual environment, an artificial lighting system was designed. This system was based on the actual lighting of the facility, that is, where the external

luminaires were installed. We tried to reproduce in the system these same illuminations, compatible not only in position, but also in intensity.

2.9. Virtual Camera Center

To enable physical security simulations, using monitoring by video cameras, virtual cameras were implemented to monitor critical points of the nuclear facility. Such cameras were positioned at strategic points, where any possible attacker would be likely to pass. The determination of such points was based on the evaluation of topographic figures, low-lying nuclear site plants and face-to-face evaluations. In the face-to-face evaluations, the main access points were observation, perimeter analysis and identification of points with greater flow of people.

To enable the user to have a more complete evaluation of monitoring through security cameras, a control center was created in the virtual scenario, which allows the visualization of all monitored points simultaneously, as showed in Figure 5. With the use of this control center, the user gets an overview of the entire facility, allowing the optimization of the positioning of security teams and avoiding unnecessary displacements within the terrain. Other advantages of virtual security cameras are that they can emit audio or visual alerts when they detect the presence of intruders. These alarms can be configured to activate a monitoring center, a siren, or a light, depending on the user's preference.

Figure 5: Control center within the virtual environment.



Source: Authors.

3. RESULTS AND DISCUSSIONS

As a case study, the Instituto de Engenharia Nuclear (IEN), a unit belonging to the Comissão de Energia Nuclear (CNEN), was chosen. IEN is located in Ilha do Fundão in Rio de Janeiro, Brasil, and it is the main state agency responsible for tailings management in the state of Rio de Janeiro. Among the main activities carried out by IEN, the production of radiopharmaceuticals, the storage of tailings and the research reactor in activity were decisive in the choice of this nuclear site for the development of these studies.

3.1. Virtual Environment Assessment

The simulator is an educational and informative tool that aims to improve the physical and nuclear safety a real nuclear facility. However, the simulator does not contain sensitive or confidential information that could compromise nuclear safety or facilitate misuse of the technology. The simulator is distributed and controlled by the institute, which verifies the suitability and quality of the content. Access to the simulator is restricted to people previously registered and authorized by the entity, who must follow a responsible and ethical use policy.

To provide the user with a strong visual identification with the existing buildings in this nuclear facility, the real positions of these buildings were maintained on the map of the institute. In the virtual model, the displacement of sidewalks, streets and entrances was adjusted according to the real environment. After that, it was positioned not only the buildings, but also trees, flower beds, fences, benches, and other objects that make up the visual composition of the institute. Figure 6 (a) shows a topographic image of the facility under study, while Figure 6 (b) shows the virtually developed based facility.

Figure 6: Comparison of the real with the virtual. (a) Topographic image of the IEN. (b) Virtual Nuclear Engineering Institute.



Source: Authors.

The modeling of existing buildings respected the actual measures and proportions of this site. The main strategic points of the IEN were modeled, externally and internally. Previous measurements were performed to support the modeling, and later, to attest to the proportionality of virtual objects.

One of the main strategic points of the institute is the ordinance one, also called the main concierge, intended for the reception of visitors. Figure 7 (a) shows a photo taken from gatehouse one and Figure 7 (b) in the virtual environment.

Figure 7: Visitors entry. (a) Photo of the main ordinance of the IEN. (b) Main ordinance in the simulation.



Source: Authors.

The ordinance two is intended for the entry of employees, thus being considered another strategic point of the facility. Figures 8 (a) and (b) show, respectively, a photo of the secondary ordinance and the model developed in the virtual scenario.

Figure 8: Employees entry (a) Photo of the IEN secondary ordinance. (b) Secondary ordinance in the simulation.



(a)

(b)

Source: Authors.

3.2. Evaluation of Virtual Cameras

At the Instituto de Engenharia Nuclear there are some areas considered as strategic points to guarantee the physical security of the nuclear facility. The points considered as priorities during the development of the present study provide intense immersion for the system user. Figures 9 (a) and (b) present a comparison of the real strategic points of the real environment with the virtual one.

Figure 9: Strategic points at the facility. (a) Point considered relevant of the facility. (b) Corresponding point in the virtual environment.



Source: Authors.

The user can view these strategic points with the interference of natural lighting and adverse weather conditions, presented in Figures 10 (a), (b), (c) and (d). For this, the climate and time system developed was applied to enable the manipulation of such characteristics. With this implementation, it was possible to perform visualizations in several test scenarios, as well as occur in true simulations.

Figure 10: Real photo with the virtual simulator. (a) Photo of a strategic point of the facility. (b) View of the virtual environment during the day. (c) View of the virtual environment in the early evening. (d) View of the virtual environment suffering climate change.



(a)



(b)



(c)



(d)

Source: Authors.

3.3. Interactive Features and Navigation Form

Figure 11 shows the simulation's initial screen where the user must choose between the modes "One User", "Multi-user" and "Exit". In One User mode, the user will control an avatar and be able to explore the map freely. In the option "Multi-user", there can be several users, on different computers and traveling through the same map where each will control its own avatar. In this mode, the user can connect to a server (local or external) and interact with up to 50 users at the same time. The Exit button closes the application.

Figure 11: Multi-user system



Source: Authors.

To run the simulator, a computer with a minimum processor requirement is required: Intel Core 2 Duo E6600 or AMD Phenom X3 8750, memory of 2 GB and video card of 256 MB or more and be compatible with DirectX 9 and Pixel Shader 3.0. Furthermore, the application can be installed or run without installation processing.

The user after making the choice in the initial menu gains control of the avatar that is initially positioned by the application at random in the area where the concierge building is located. Here's a list of controls that a user can control the avatar with to get around:

- "W" key - forward walk
- "A" key - walks to the left
- "D" key - walks to the right
- "B" key - toggles between third- and first-person views
- "C" key - Lower
- "1" key - enables weather and weather controls

- "Shift" key - run
- "Space" key - jump

The multi-user system can be used in conjunction with virtual cameras, implemented in the environment, for training and simulations of invasion in the facility. The main objective is to maintain the degree of security determined in the strategic planning of the security company.

3.4. Control Systems

Figure 12 shows the menu that allows the control of the time in the environment. It allows the experience of using the application in the morning, afternoon or night of the day. It is possible to choose the exact time using the slider at the top. Also adjust so that the transition between day and night occurs automatically and for a time set by the user.

The climate system allows the choice of some climates that can enrich the experience during the use of the application. In this menu, the user can also turn on and off the artificial lights of the poles distributed on the ground. The control of the weather and weather system is done with the mouse.

Figure 12: Weather and climate system adjustment menu.



Source: Authors.

4. CONCLUSIONS

This article aimed to show the development of a computational model (virtual environment) that serves as an aid tool for the study and definition of physical safety strategies of nuclear facility. In this sense, the first specific objective of this work was to evaluate the computational model constructed as to the degree of realism of its physical structure when compared to the real environment. Finally, the second specific objective is to evaluate the same as some security features when compared to the actual environment.

The degree of realism of the developed virtual environment was analyzed according to the proportion and size compared to the real world. Firstly, through images, the facility and its virtual buildings (camera view) were compared with the real environment (photos). It was observed that the proportions of the real environment and the objects inserted in it in relation to human beings were equivalent to the proportions of the avatars inserted in the environment.

Thus, the results achieved in the evaluation regarding the quality of reproduction allowed us to conclude that the VR tool used to model the virtual scenario and interact with it was able to create a nuclear facility with a good degree of realism.

To evaluate strategies in different scenarios, controls were inserted into the system to adjust the configuration of the virtual environment, such as varying weather conditions, changing real and artificial lighting and different observation angles of the system, using surveillance cameras. Thus, as occurs in real training and simulations, it is possible to evaluate the reaction of safety agents in adverse situations and conditions.

Thus, the results achieved in the evaluation regarding the relevance of reproduction allowed to conclude that the situations reproduced through the virtual reality tool have the potential to be used to assist in the planning and definition of physical safety strategies of nuclear facilities and, thus, optimize the process and the execution time of tasks.

Finally, from the results presented, the article achieved its purpose of serving as a complementary tool to the planning of the physical safety of nuclear sites, enabling the performance of simulations and training without interfering in the operation of the facility, and without exposing individuals to risks of radiological contamination, in face of several possible scenarios. Furthermore, virtual training offers several advantages, such as flexible scheduling, the possibility of accessing updated and interactive content, and the reduction of installation financial costs.

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CONFLICT OF INTEREST

All authors declare that they have no conflicts of interest.

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