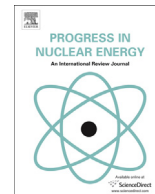


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Using virtual reality to support the physical security of nuclear facilities



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ABSTRACT

The Brazilian nuclear program has reinforced the importance of improving the physical security of nuclear facilities located in this country. Thus, the present work proposes the development of a new tool that allows the user to make interactions inside a virtual environment, which simulates the nuclear facility's structure, in order to aid on planning action strategies to improve its security. For such, a virtual model of the Brazilian nuclear research center known as Instituto de Engenharia Nuclear (IEN), located on Ilha do Fundão – Rio de Janeiro was developed. It is defined as a 3D model with a high degree of fidelity to the real environment in which it is based. Inside this model, characters known as avatars can move and interact in real time. Situations that could affect invader's visibility and detection such as natural and artificial illumination, climate and shadows can be represented with realism. In addition, the tool has a virtual CCTV surveillance system that allows environment supervising. Thus, the system makes possible strategies simulation, allowing an evaluation of the performed procedures as well as assisting in the training of security personnel in nuclear and radioactive installations.

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1. Introduction

Nuclear safety refers to a set of procedures implemented by countries and international organizations in order to assure a security pattern concerning to handle, use and storage of radioactive materials (IAEA, 2006). The security of facilities that are used to store or generate such materials must be performed with great attention. Moreover, it requires strategies that must be created, tested and improved to keep these materials and all information related to the total amount of nuclear material and its location away from terrorists or hostile nations.

The development of strategies like that demands time, financial resources and the engagement of a large group of people. For this reason, they need to be tested in exercises simulating real situations to know if there is compatibility between the theoretical defense plans and the real conditions of the nuclear facility.

Therefore there is a need to evaluate parameters like the nuclear facility's ground topology; the visibility level of the its area and borders; the number of members compounding the defense crew (security agents); equipments for detection of radiation and the time spent to reach a compromised position, just to give some examples (Stackpole and Oksendahl, 2010).

Concerning to this matter, the use of Virtual Reality (VR) techniques on planning the actions related to the safety strategies can contribute to improve the simulated results as shown in (Gatto, 2012), (Mól et al., 2008a), (Freitas et al., 2011), (Gonçalves et al., 2010), (Aghina et al., 2007), (Mól et al., 2008b), (Jorge et al., 2007), (Louka et al., 2005), (Mól et al., 2007), (Mól et al., 2008c), (Jorge et al., 2011) and (Xi et al., 2009).

Thus, this work proposes the development of a computational model using virtual reality techniques which is intended to describe as detailed as possible a real nuclear facility in order to perform simulations of physical security strategies. The objective is to analyze the feasibility on using software for development of games to create such model, described as a virtual environment, which will be used as a study auxiliary tool to define security strategies for nuclear facilities. The paper is organized as follows: Section 2 describes virtual reality basic concepts, virtual environments and avatars.; Section 3 presents the methodology employed in this work;

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Section 4 discuss the tests with the results and analysis, considering proportionality, different vision angles and the time displacements spent on both real and virtual environments. Finally, Section 5 is dedicated to final considerations and conclusion.

2. Virtual Reality

Virtual Reality (VR) is defined as a group of technologies and techniques developed to integrate both user and computational systems. Its objective is to give to the user the feeling of be living inside a virtual world in real time by means of advanced interfaces. Thus VR can be seen as an experience between user and computational systems in 3D.

In other words, VR is an interface that allows the user to access computational applications in real time besides giving him the opportunity to visualize, make movements and interactions inside virtual environments built by the computer, employing multi sensorial devices to do so (Kirner and Siscoutto, 2007).

This concept was firstly employed by the United States Air Force just after the end of World War II, with flight simulation purposes. Due to this initial application, the VR was intended to isolate the user of the real world. Nowadays VR can be commonly found in a great variety of applications such as virtual modeling, ergonomic studies and, with higher intensity, VR is used on the entertainment industry to create games, movies and animations (Francis and Tan, 1999). The great range of VR applications make it possible to be classified according to the way in which the user will interact with the virtual environment. There are two classes: Immersive VR (IVR) and Non-Immersive VR (NIVR) (Burdea and Coiffet, 2003).

The objective of IVR is to merge the user inside the software's environment as far as it is possible, giving him the feeling of complete isolation of the real world. To do that, special technologies are used in order to block up the user's perception. IVR intends to create a more intuitive way of dealing with the virtual world allowing the user to look around by moving his head and giving him space perception by emulating the human view, for example.

Moreover, IVR tries to make the user recognize sound orientations by locating its source based on direction and distance like it is done at the real world besides it gives him the opportunity to communicate through gesture and voice commands (Haguenauer et al., 2011).

On the other hand, NIVR does not require the total isolation of the user. So, regular devices like monitors, keyboards, mouse and others are used. However there are interfaces in which the user is partially isolated from the real environment in a hybrid procedure using both, conventional and non-conventional devices. In such

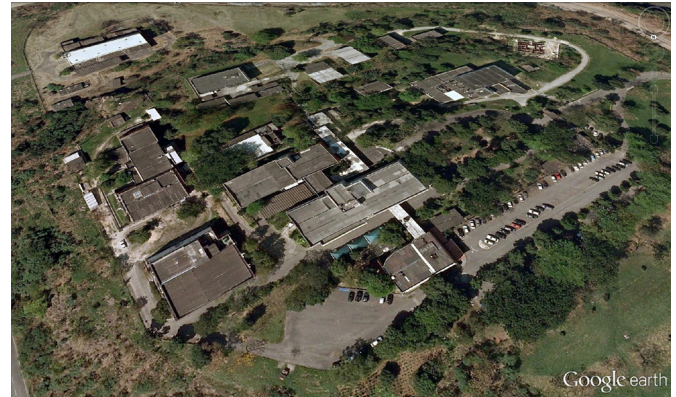


Fig. 2. IEN's aerial image.

cases it is proposed the Half-Immersive classification (HIVR) (Burdea and Coiffet, 2003).

3. Methodology

This work proposes a two-phased method. The first is named “environment modeling”, which consists on building the virtual environment itself. It is done by means of two softwares: Unity 3D and AutoDesk 3ds Max. Whereas the plot of the ground is performed by Unity 3D, AutoDesk 3ds Max is used to create edifications like near buildings and the facility itself.

The last phase is called “functionalities implementation”. It consists on the addition of auxiliary devices for the Unity 3D nucleus, like virtual cameras, aiming to allow it to fulfill the purpose intended in this work. Such functionalities are made to be part of Unity's nucleus by means of a parameters configuration using C#.

3.1. Environment modeling

3.1.1. Edifications

The edifications modeling is performed by AutoDesk 3ds Max. A topographic image was added to this software to be used as a model for the studied area. To define how high each building is, it was used a rough's calculation method based on a comparison using photos took at the very place of study. This was how the height values used by AutoDesk 3ds Max were found.

There was also the need to build the interior of each building due to the high number of people who access IEN installations every day. The same technique using photos and comparisons was

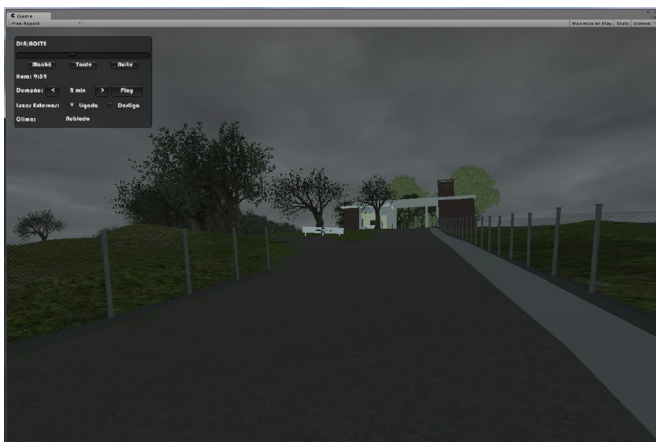


Fig. 1. Weather menu.



Fig. 3. IEN's virtual model.



Fig. 4. Real camera photograph of the facility.

also used to develop the interior modeling of the buildings. Generic objects like chairs, computer desks, sinks and others were added to the environment by means of free files downloaded at specialized websites. More specific objects like windows and closets were also modeled using Poly Modeling technique.

The second stage refers to texture application. Texture layers were applied to the objects using AutoDesk 3ds Max in a procedure based on photos took at place of study. Parameters like natural effects, moisture and dust were used to give a more realist aspect.

3.1.2. Terrain modeling

Unity 3D was used to generate the nuclear facility's terrain modeling. Firstly, a regular terrain was developed using the basic tool provided by the software. Then it was changed to be in agreement with the dimensions of the real facility's site. So, parameters like width and length of the virtual terrain were adapted to the ones of the real site. After the development of the virtual terrain, the addition of edifications and generic objects was performed. It was done by importing 3D objects created by Autodesk 3ds max and brought to the virtual terrain of Unity 3D. Finally, virtual characters known as avatars were created in order to interact with the developed environment.

3.2. Functionalities implementation

3.2.1. Avatar's characteristics

The basic characteristics of the pattern avatars provided by unity 3D had to be changed in order to give a more realistic experience

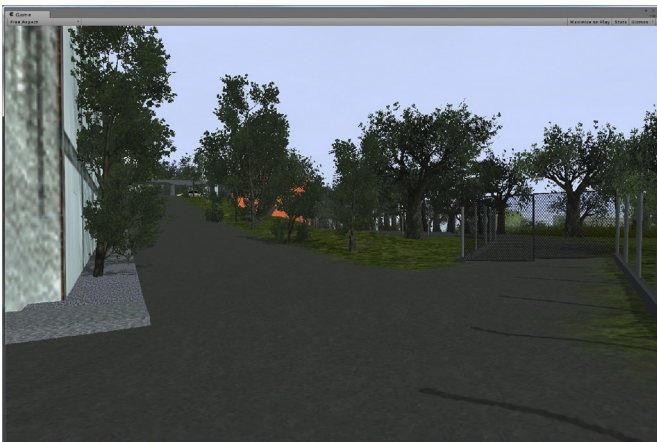


Fig. 5. View of the Virtual camera at the same position.

Table 1
Facility's displacement routes.

Route	Description
Route 1	Displacement from entrance main hall to second entrance hall
Route 2	Displacement from main entrance hall to the nuclear reactor building
Route 3	Displacement from main entrance hall to the wasting storage building
Route 4	Displacement from main entrance hall to VRLAB building
Route 5	Displacement from second entrance hall to the nuclear reactor building
Route 6	Displacement from second entrance hall to the wasting storage building
Route 7	Displacement from second entrance hall to VRLAB building

for the user. Furthermore, parameters like the character's motion speed and its jump height were adjusted based on real measurements. The avatars are also allowed to alternate between first person view and third person view. Hence the user can choose the best viewing according to its needs when using the proposed application.

3.2.2. Day and night system

Different climate conditions are also considered in this work. It is done by a plugin known as Unistorm to insert natural characteristics like illumination, shadows, sun positioning, and presence of stars and even moonlight to the developed environment.

It's possible to make changes on the weather conditions as well. So, the user can alternate between sunny days or cloudy ones besides the use of rain, wind, snow and other ones. Therefore it's possible to achieve simulations in a great range of sceneries. There was the need to develop a control menu to perform the management of the previous mentioned weather characteristics. It is shown in Fig. 1. Thus the user can define it by an option list developed with this purpose.

3.2.3. Artificial illumination

The real illumination points were defined using photos and making observations of the nuclear facility's site. Then an artificial illumination system was inserted at the virtual environment. The objective was to reproduce the real illumination characteristics inside the virtual facility. The virtual environment illumination system is scheduled to automatically turn on at 6 pm and to turn off at 6 am. However, it is allowed to the user the blackout option, in which it's possible to turn off the entire artificial illumination at once.



Fig. 6. (A) Main entrance hall; (B) second entrance hall; (C) VRLAB – Virtual Reality Laboratory; (D) Argonauta Nuclear Reactor; (E) Wasting storage building.

Table 2

Actions, real time, simulation time, average time of simulations and route's 1 relative errors.

Action		Simulation 1 (s)	Simulation 2 (s)	Simulation 3 (s)	Simulation 4 (s)	Simulation 5 (s)	Average time of simulations (s)	Relative error (%)
Walking	Real	96.3	102.1	92	95	95.7	96.2	Walking
	Virtual	91.6	91.1	90.3	88.9	92.7	90.9	5.5
Running	Real	39.4	42.8	40.9	38.1	44.3	41.1	Running
	Virtual	38.3	39.4	37.7	38.8	38	38.4	6.5

Table 3

Actions, real time, simulation time, average time of simulations and route's 2 relative errors.

Action		Simulation 1 (s)	Simulation 2 (s)	Simulation 3 (s)	Simulation 4 (s)	Simulation 5 (s)	Average time of simulations (s)	Relative error (%)
Walking	Real	97.1	94.9	104.2	96.7	100.9	98.8	Walking
	Virtual	93.2	94.7	91.9	91.8	93.6	93.0	5.8
Running	Real	39.1	39.9	43.3	43.9	42.1	41.7	Running
	Virtual	40.1	39.7	40.4	41.3	38.9	40.1	3.8

3.2.4. Camera system

This work implements a virtual camera system which aims to simulate physics safety conditions. These cameras are placed in critical positions of the nuclear facility, e.g., strategic points that are likely to be invaded by non-authorized personnel. To define critical positions aerial images, blueprints of the nuclear site and personnel valuations were used. Such procedure consisted on observing the main accesses routes, perimeter analysis and also on the identification of the places where there was a major flux of people.

The user has the opportunity to visualize all the monitored points simultaneously by means of a control cameras center, which has been inserted at the virtual facility to allow him to make a more complete observation of it. It contributes to optimize the security team positioning thus avoiding unnecessary displacements.

4. Tests and results

The Brazilian nuclear research center known as Instituto de Engenharia Nuclear (IEN) was considered as the case of study to this work. It's an institution with purposes of research, development and innovation on nuclear issues located in Rio de Janeiro, Brazil. Due to its importance to the Brazilian's nuclear activities, it was used as a model for the virtual nuclear site proposed in this work.

4.1. Virtual environment valuation: proportionality

The virtual environment developed in this work intends to be as similar as possible to the real installations of IEN. Thus the measure values used on the construction of the referred virtual scenery have been based on maps, blueprints and photos of the real buildings of this facility.

4.1.1. The facility

Aiming to provide to the user a more realistic experience, the positioning of the buildings compounding the virtual site have been done respecting its real positions when observing the facility's

map. Fig. 2 shows a topographic image of IEN whereas Fig. 3 presents the virtual model of it.

4.1.2. Near buildings

The modeling of each building near to the analyzed facility has respected both proportions and measures of the real site. Unity 3D scale was used to do it. Two of the main critical positions of the facility were modeled in a more detailed way not only externally but also concerning to their interior.

In such specific positions, it was necessary to assure a major environment detailing. This is due to a greater number of interactions performed by the avatar when it is visiting each of these particular regions. One of these critical positions is the entrance hall number one, where visitors are received.

The entrance hall number two is used by the employees, thus being considered another critical position of the facility. The avatar has also been developed in order to be in agreement with the facility's proportions.

4.2. Virtual environment evaluation concerning to the observation points

There are lots of viewing angles in a real facility. It is possible to inspect the facility's site by means of patrols, security cameras and by observing specific points of interest. These different viewing angles can be changed according to the variation on illumination and meteorological conditions, which can influence on the environment's visibility.

4.2.1. Strategic points of view

Some places at IEN's site can be considered as critical ones as they can be used to guarantee the physical security of the whole facility. When on these points the user can simulate natural illumination changes. To do so, it was developed a day-and-night system using Unistorm software. It allows the user to make simulations in the most diverse sceneries.

Table 4

Actions, real time, simulation time, average time of simulations and route's 3 relative errors.

Action		Simulation 1 (s)	Simulation 2 (s)	Simulation 3 (s)	Simulation 4 (s)	Simulation 5 (s)	Average time of simulations (s)	Relative Error (%)
Walking	Real	150.2	165.3	158.3	155.4	162.8	158.4	Walking
	Virtual	145.5	148.1	147.2	147.9	145.8	146.9	7.3
Running	Real	67.6	69	70.7	67.8	71.1	69.2	Running
	Virtual	60.7	61.7	63.4	61.4	61.3	61.7	10.9

Table 5

Actions, real time, simulation time, average time of simulations and route's 4 relative errors.

Action		Simulation 1 (s)	Simulation 2 (s)	Simulation 3 (s)	Simulation 4 (s)	Simulation 5 (s)	Average time of simulations (s)	Relative Error (%)
Walking	Real	167.9	171	163.6	167	165.7	167.0	Walking
	Virtual	161.2	163	160.8	160.9	162.4	161.7	3.2
Running	Real	74.2	76.4	76.1	77	74.9	75.7	Running
	Virtual	71.9	70.4	72.7	73.4	73.8	72.4	4.3

Table 6

Actions, real time, simulation time, average time of simulations and route's 5 relative errors.

Action		Simulation 1 (s)	Simulation 2 (s)	Simulation 3 (s)	Simulation 4 (s)	Simulation 5 (s)	Average time of simulations (s)	Relative Error (%)
Walking	Real	48.3	50.1	46.3	47.7	50.5	48.6	Walking
	Virtual	44.7	44.4	42.1	45.7	46.1	44.6	8.2
Running	Real	24.7	22.1	23.4	27.1	25.9	24.6	Running
	Virtual	22.3	21.7	24.7	22.7	22	22.7	8.0

Table 7

Actions, real time, simulation time, average time of simulations and route's 6 relative errors.

Action		Simulation 1 (s)	Simulation 2 (s)	Simulation 3 (s)	Simulation 4 (s)	Simulation 5 (s)	Average time of simulations (s)	Relative error (%)
Walking	Real	115	112.1	113.3	115.3	114.5	114.0	Walking
	Virtual	109.1	108.7	109.3	110.8	109.4	109.5	4.0
Running	Real	60.1	65.7	63.4	63.1	62.8	63.0	Running
	Virtual	60.7	60.4	61.5	62.1	62.3	61.4	2.6

4.3. Camera view

The virtual cameras are placed at the same positions in which the real ones are in order to compare the images generated on both real and virtual environments. The images of the real environment were used to validate the ones generated by the virtual cameras. As shown in Figs. 4 and 5 there is a great similarity between them, which validates the proposed method.

4.4. Time displacement evaluation

To validate the avatar's moving inside the virtual nuclear site it time displacement measures were performed on both real and virtual sceneries along paths of equal lengths. The analyzed routes are shown in Table 1.

Fig. 6 shows the localization of the buildings inside IEN's site. They were used as a reference to calculate the time spent on the virtual environment. This experiment gave the number of steps used by an adult man. Moreover, it was achieved the time spent when he was walking and running at 12 km/h.

The next tables show the obtained results. Table 2 presents the data referred to route's 1 measurements. To accomplish it, it's necessary to fulfill 125 m, which is roughly the same as 179 steps.

Table 3 presents the data referred to route's 2 measurements. To accomplish it, it's necessary to fulfill 136 m, which is roughly the same as 191 steps.

Table 4 presents the data referred to route's 3 measurements. To accomplish it, it's necessary to fulfill 207 m, which is roughly the same as 288 steps.

Table 5 presents the data referred to route's 4 measurements. To accomplish it, it's necessary to fulfill 230 m, which is roughly the same as 312 steps.

Table 6 presents the data referred to route's 5 measurements. To accomplish it, it's necessary to fulfill 65 m, which is roughly the same as 92 steps.

Table 7 presents the data referred to route's 6 measurements. To accomplish it, it's necessary to fulfill 160 m, which is roughly the same as 219 steps.

Table 8 presents the data referred to route's 7 measurements. To accomplish it, it's necessary to fulfill 130 m, which is roughly the same as 180 steps.

5. Conclusion

This paper proposed to verify the feasibility of using a game's development tool to create a computational model, a.k.a. virtual environment, with purposes of study and implementation of physical safety for nuclear facilities. Therefore, the objectives of this survey were to evaluate the referred model concerning to the level of realism of its physical structure when compared to the real environment as well as to assure its security functionalities.

Table 8

Actions, real time, simulation time, average time of simulations and route's 7 relative errors.

Action		Simulation 1 (s)	Simulation 2 (s)	Simulation 3 (s)	Simulation 4 (s)	Simulation 5 (s)	Average time of simulations (s)	Relative Error (%)
Walking	Real	99.8	99.1	96.7	95.1	100.7	98.3	Walking
	Virtual	94.2	95.7	92.9	96.7	95.1	94.9	3.4
Running	Real	44	41.9	46.4	39.8	41.5	42.7	Running
	Virtual	41.9	44.3	42.8	45.6	44.2	43.8	2.4

To do so, the realism degree of the developed environment was defined with basis on both proportion comparisons and time displacement analysis. Firstly, a comparison between the real nuclear facility's site, namely the Brazilian nuclear research center known as IEN, and its virtual match was performed. It was observed that the images generated by the virtual cameras kept a proportionality which is equivalent to the one observed by photos of the real facility.

The speed of the avatars when running or walking by particular routes inside IEN's site was evaluated using the required time displacement to fulfill them as parameter. In order to do that, the same route was used in both real and virtual environments. As shown by results of the previous section, the time spent was almost the same concerning to simulations on real and virtual environments.

Thus the achieved results have confirmed that the virtual reality tool used to modeling the virtual environment and to make interactions inside it was able to build a nuclear facility with acceptable realism level which is reflected by a good similarity between the virtual model and the real nuclear facility's site.

The proposed method also allows the user to evaluate physical security strategies in a variety of sceneries by changing weather conditions, natural and artificial light sources besides the observation of different points of view inside the virtual model. It can contribute to evaluate security agent's reaction when facing abnormal conditions or situations.

In other words, this work achieved its purposes of being useful as an auxiliary tool for planning the physical security of a nuclear site, allowing the user to perform simulations and training without interfere on the facility's working or expose employees to radiological risks, under a variety of sceneries.

Acknowledgments

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