Using Artificial Neural Networks and Actual Area Radiation Monitors to Estimate Dose in a Virtual Environment

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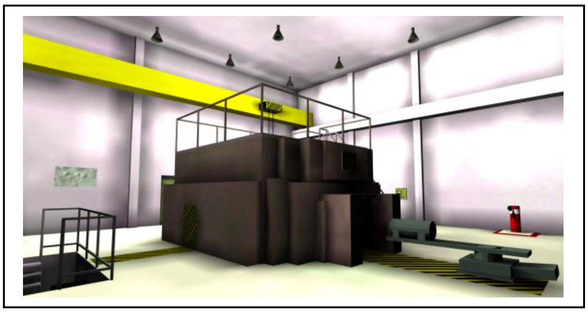

Figure 1: Virtual Argonauta

Abstract

It was observed in recent years the need to create a virtual environment of Argonauta research reactor, located at the Instituto de Engenharia Nuclear (IEN). This virtual model was developed at the institute and is known as Virtual Argonauta (VA). This three-dimensional model is used in training exercises and simulations, where the characters (avatars) move and interact with the environment. One of the possible simulations is related to the monitoring of doses absorbed by radiation sources. In this work the monitoring is performed in real time, through the area radiation monitors (ARM).

This work aims to create a dedicated system to the determination of radiation dose, according to the positioning of the avatar inside the reactor hall of the Argonauta. Using a set of actual measurements obtained from the interior of this hall was developed and trained a module artificial neural network (ANN) for determining the absorbed dose by the character on each point of the environment. The ANN receives as input parameters: the avatar position, the reactor power and data from actual radiation detectors present in this installation.

The result shows the interpolating function, from the extracted ANN, when inserted in the virtual model demonstrates the continuous profile of the radiation and allows the user to interact with the environment without exposing it to this.

Keywords: virtual reality, neural network, Argonauta, radiation monitor.

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1. Introduction

The concern for safety in nuclear installations has been growing over the years, especially regarding the physical integrity of people and sites. Several existing standards and procedures are intended to ensure such security. According to the ALARA (As Low As Reasonably) [ICRP Publication 60 1990] the radiation exposure, when necessary, should be as low as reasonably achievable. This standard aims to ensure minimizing the dose and the compliance with established limits for radiation dose [ICRP Publication 60 1990], thus safeguarding the receiving non-harmful.

The facilities defined as controlled areas are those with high levels of radiation, requiring strict control and monitoring. In some places workers must stay the shortest possible time, or their presence may be vetoed, in order that their dose limits remain within the limits established by CNEN-NN-3.01. In situations where a worker is exposed to high doses of radiation in a short period of time, this will be away for a period (proportional to the dose received) from activities that may expose you to new doses. Among others, instant monitoring equipment of radiation levels is used to carry out this control.

Techniques and methods that allow the estimation of radiation doses absorbed by an individual are of great value in this context. Thus, pre-planning of activities to be carried out in controlled areas is essential to ensure that dose limits are respected. Given this scenario, the present work proposes that computational simulations of activities involving radiological exposure be performed, allowing a prior estimate of doses absorbed by workers without the need for actual exposure. These simulations also contribute to the planning of activities and eminent risk assessment of health workers and for evaluation of existing installations and not yet built, identifying problems, constraints, etc.

2. Related Work

Several recent works have used VR for simulations and training. We can cite, among them the works listed below.

Virtual Reality System for Evacuation Training, developed by Mól. et al. [2008], allows the realization of training and simulation of evacuation sites with large concentrations of people. Using the Unreal Engine 2 Runtime, the system was adapted to comply the speed of movement of avatars according to patterns next to human standards and can be controlled in the network by multiple users interacting in the same scenario, providing accuracy to evacuation trainings.

Other related work is Virtual Reality System of CIPRES Project, which allows the training of operators in nuclear facilities simulating refueling operations [Ródenas et al. 2005]. Such system was used in the training program of the CIPRES project, with the objective of minimize the time of operations and reduce the doses received by workers.

3. Virtual Reality

Virtual reality, also known as VR, allows the integration of three basic ideas: immersion, interactivity and involvement. The immersion is associated with the feeling of being present in the environment, the interaction is the possibility for the user to manipulate virtual objects, and involvement determines the degree of motivation with this activity. Thus, providing recreating the feeling of reality for an individual [Augusto et al. 2007].

3.1 Unreal Engine

The program chosen for the virtual environment development was the Unreal engine (Epic Games, Inc), whose core game can be modified to fit this project.

The Unreal Engine has been chosen because it produces virtual environments with visual quality and realism due to its core 3D, uses avatars to represent users in the virtual environment, and has an own scripting language called UnrealScript.

4. Artificial Neural Network

Artificial Neural Networks (ANNs) are computational techniques consist of a mathematical model inspired by the brain structure, with the premise that knowledge is established through experience. One is composed of several artificial neurons, which are interconnected by communication channels (analogous to synapses) associated with certain weights. The knowledge of the ANNs are given from the interactions between neurons that compose the network.

The ANNs can present different characteristics, varying according to its architecture and neurodynamics used, among other factors. For architecture means the arrangement of neurons form their connections in the network formation, and neurodynamics specifies the functions of internal activation of neurons and the type of training that these are subject [Haykin 2001].

4.1 Radial Basis Functions Networks

Are known by Radial Basis Functions Networks (Radial Basis Function - RBF), ANNs using radial basis functions in their neurons of the intermediate layer. This layer is intended to separate the data into groups of similar characteristics, making the entries standards not linearly separable in a set of linearly separable outputs. The output layer is intended to classify the received pattern.

The RBF are those whose value increases or decreases with distance from a central point. Usually such functions have their high value and not negative at some point $\propto$ of its domain and decreases to near zero when the distance between point x and the center point tends to infinity, according to the norm $||x - \propto||$. The RBF used most commonly described below.

$$\text{Gaussian function}: f(\omega) = e^{-\frac{1}{2}\frac{\omega^2}{\sigma^2}}$$

$$\text{Multiquadratic function}: f(\omega) = \sqrt{\omega^2 + \sigma^2}$$

The term $\omega = ||x - \propto||$, usually provided by the Euclidean distance, x as input vector e, $\propto$ and σ respectively as the center and width of the radial function. For these premises, the Euclidean distance W $= ||x - \propto||$ of the input vector to the central point is the input to the function that returns the value of the activation from the intermediate layer, culminating in the response generated by a neuron j of output layer respecting the following expression:

$$y_j = \sum w_{ji} \cdot f(\omega)$$

In a RBF the learning process is related to the optimization of linear weights associated with each output unit and also the activation functions of nonlinear intermediate layers. Due to the fact of the intermediate and output units perform different processes is indicated that the optimization process be implemented by different methods in each of them (hybrid training, divided into two stages). In the first stage of training the amount of radial functions and its parameters are determined through unsupervised methods, placing the centers in regions of space where the most representative input vectors are located. In the second stage the weights of synapses will be adjusted. Due to the outputs of the intermediate layer constituting a vector linearly separable, the weights can be determined by linear models.

4.2 GRNN Architecture

The architecture "General Regression Neural Network" (GRNN) corresponds to a feedforward network based on RBFs using supervised training, and commonly with four layers.

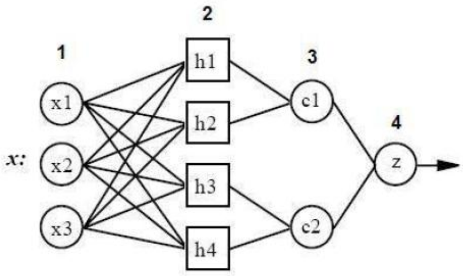

Figure 2: Typical diagram of a GRNN network

The *Input Layer* is a neuron for each input variable. For categorical variables, there are N - 1 neurons, N being the number of categories. Normally uses the weight of each neuron as unitary, and can also be standardized. The outputs of these layer neurons feed each neuron in the hidden layer.

In the *Hidden Layer* (second layer) is one neuron for each training vector. Each neuron calculates the distance between the input vector and the vector of training. This distance feeds the probability density function of each neuron, and the weights of these, are sent to the next layer (*class nodes*).

The third layer of GRNN corresponds to layer classification or *Class Nodes*. In this layer, by default, there are only two neurons, known as the numerator and denominator. In the numerator adds up actual weight, that is, values multiplied by the target value for each hidden neuron. In the denominator is the added weight of the values from each of the hidden neurons.

Finally, the fourth and last layer is called *Decision Layer*, responsible for splitting the accumulated value in the numerator by existing unit value in the denominator and uses this result as a target value set.

5. Methodology

This chapter will present the methodology developed to estimate the dose rate in a specific area and insert it in the virtual environment.

5.1 Estimation of Dose Rate

The estimation of the radiation dose is achieved by detectors installed at points previously chosen. This estimate is hampered, among other factors, by the interaction of radiation with present objects and the singularity of each installation. With this, it's necessary algorithms able to interpolate data, measured and tabulated, with characteristics typically nonlinear.

5.2 Area Radiation Monitoring in Real Time

Area Radiation Monitors (ARM) are detectors installed in the installation to measure different types of radiation, including gamma, alpha and neutrons. The data from these detectors will feed a table of dose to be used for interpolation of radiation.

The radiation monitor MRA 7027 [Oliveira et al. 2000] is a digital area monitor that can be connected to different types of sensors to monitor environmental radiation. Normally it's used in conjunction with the probe Geiger-Müller SGM 7027 to detect gamma and x-rays, and can also be used with other probes, such as SPQ 7026 for detecting surface contamination of alpha, beta and gamma. The MRA 7027 can be used alone as a radiation monitor area, as it can be used in network with other monitor connected to a supervisory computer through its serial communication channel.

Figure 3: Radiation Monitor MRA 7027 in conjunction with the probe Geiger-Müller SGM 7027

5.3 ANN Trained in Virtual Environment

A new class has been programmed with the UnrealScript language to insert a neural network in Unreal. The ANNs trained generate interpolation functions, each one referring to an area, which when inserted into the program cover the entire area of locomotion of the avatar.

6. Case Study: Argonauta Reactor

This work was developed based on the premises of the Argonauta Research Reactor of IEN. This reactor has an output channel, called J9, which irradiate research objects, releasing gamma radiation in the environment (this reactor is shielded to hinder the release of radiation to other locations).

In this application was acquired only the dose range measures of the reactor and the interpolation by ANN employing the GRNN architecture. With the networks trained and tested, three interpolation functions in programming language C + + were generated. After an adaptation was made for these functions to the UnrealScript language, that is the language used in Unreal. These functions were then entered as calculation of dose received by the avatar. The result is that from data such as: position of the avatar, Argonauta reactor power and the measure of fixed radiation detectors, it is possible to calculate in real time the dose received by a virtual user.

6.1 MRA 7027 in network with the Unreal Engine

A system which connects the data area detector with the inserted code in Unreal was developed, thus feeding the ANN. In this system, the two passive servers have communication only with the ARM and the Unreal, being interconnected by a third system called "Man in the Middle" (MIM). The process MIM receives data of dose from the first system and sends it to the second system.

The server collects the measured data of the ARMs detectors is labeled "ARM server." These data are published on the network using the Apache software, being called "Apache server" (first process). The server Unreal Engine2 Runtime uses a proprietary implementation to run the game server, this is identified as "Unreal server" (second process). The computers where users participate in a particular simulation are labeled "Unreal clients". Finally, the figure below shows this linking.

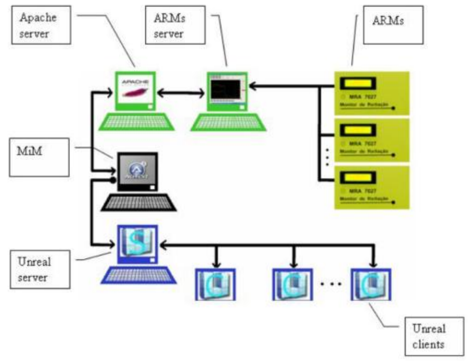

Figure 4: Communication scheme between ARM and Unreal

6.2 Results

The following image shows the program running, and it is possible to visualize the gamma dose received by the avatar. This dose received depends on the position of the avatar, reactor power and the measure of the fixed detectors.

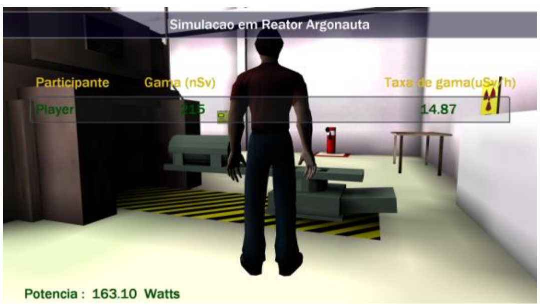

Figure 5: Received gamma dose accumulated by the user

7. Conclusion

In the present work was developed a system for predicting radiation doses to a virtual environment, so that the information on the dose of the real environment is inserted into the virtual in real time. Radiation dose measures were estimated at continuous profile interpolated by artificial neural networks and inserted into the core of Unreal, allowing a connection of the actual installation with the simulation achieving the main purpose. The proposed methodology was applied in the reactor hall of the Argonauta, and it was possible to monitor, in real time, the dose of gamma radiation and show at the core game.

The interpolation provided a quantitative analysis of the average gamma dose inside the hall of the Argonauta reactor and with these measures making possible the training of employees, thus minimizing exposure to high levels of radiation.

As future works is expected the implementation of occupancy sensors or cameras with pattern recognition in the reactor room, allowing the virtual monitoring of an employee in the real environment. Another study is to measure the dose rate at different heights in the interpolate space and R^3, allowing to estimate the dose in each area of the human body.

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