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ORIGINAL ARTICLE

Design of a collaborative virtual environment for training security agents in big events

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Abstract This paper describes a design of a collaborative virtual environment (CVE) for training security agents in big events. The CVE was modelled with Autodesk 3ds Max, while Unity 3D was used to create the terrain and implement the features that make up a virtual environment. The Brazilian soccer stadium known as Maracanã and its surroundings were chosen as the real counterparts of the CVE. The usability of the CVE was evaluated through simulations involving security agents dealing with threats related to suspects carrying radioactive material in big events. In order to perform these simulations, we use the same procedures used during 2014 FIFA World Cup and planned to be used in Rio 2016 Olympic Games. The main objective of this work is to verify the feasibility of designing a CVE and its usability for training security agents involved in big events issues. Results indicated that the proposed CVE has been successful concerning both, design and usability, besides of helping to improve the ability of each member of the security team on performing his duty.

Keywords Virtual reality · Collaborative virtual environment · Usability · Design

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1 Introduction

The recent terrorist attacks on "soft targets" (Forest 2006) defined as civilian sites where people are vulnerable and congregate in large numbers such as national monuments, hospitals, schools, sporting arenas, hotels, cultural centres, movie theatres, cafés and restaurants, places of worship, nightclubs, shopping centres and transportation sites indicate the need to improve security countermeasures in place to provide a high degree of people protection against such attacks. As these sites are not designed in safe basis to provide adequate physical barriers, well-trained security agents to prevent and respond to such situations become very important to avoid or mitigate security issues. Therefore, there is a need to provide training to develop create and develop skills for security agents through simulation exercises.

Simulation exercises serve as imaginary future situations to explore possible responses to events. Thus, such exercises should be planned to address the cognitive skills that must be developed to respond expected and unexpected situations. The purpose and scope of these exercises may include the training of emergency responders, providing practice opportunities in new situations, evaluation of new technological systems, building trust on trainees, identifying critical decisions, improving coordination and testing the plans in the light of new threats (Voshell 2009). One of the possible ways to accomplish this type of training is through the use of virtual reality (VR).

VR concepts are very attractive to the users as it allows to them the feeling of immersion without being exposed to any risk. In addition, the use of such technologies can offer virtual environment for simulations at unfinished facilities or at the ones where the access is restricted. Virtual environments may also contribute to improve the planning of security tasks and procedures. Therefore, this work proposes to verify the feasibility of designing a collaborative virtual environment (CVE) in which simulations of several types of scenarios in big events can be performed to enhance the security agents' skills.

The development of a virtual environment comprehends scenarios definition, avatars selection and the choice of suitable tools that will be used for its modelling. Moreover, there is a need for a game engine, used to implement the functionalities available in the virtual environment. The complexity referred to the development of such environments is mostly related to the real-time rendering of its objects as well as the interaction user environment.

The environment modelled was the Maracanã stadium and its surroundings, more precisely the place where Bellini's statue and the access ramp are located. The choice of a stadium as a scenario is because it is where big events take place, such as games and shows which makes it possible to train agents who will perform security procedures in other stadiums.

The developed CVE was tested with simulations that involved several scenarios for identification and approach suspects of carrying hazardous materials. The scenarios propose particular situations that require different strategies and collaborative aspects/competencies to capture suspects, and were created based on interviews with specialists (security agents) who have worked in 2014 FIFA World Cup Brazil™ and Rio 2016 Olympic Games.

The simulations performed, besides testing the CVE as a valuable training tool, also contributed to test the usability of the design. The paper is organized as follows: Sect. 2 describes virtual reality basic concepts; Sect. 3 presents the basic concepts related to collaboration; Sect. 4 describes collaborative virtual environment basic concepts; Sect. 5 describes the CVE design; Sect. 6 details the methodology employed to test and evaluation CVE; Sect. 7 discusses the tests with the results and its analysis. Finally, Sect. 8 is dedicated to final considerations and conclusion.

2 Virtual reality

There are several ways to define virtual reality (VR). Maybe the simplest is to describe it 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 (Silva et al. 2015). According to Kirner and Siscoutto (2007), 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.

The VR concept for training purposes was firstly employed by the US Air Force after the end of World War II, with flight simulation purposes (Rid 2009). Nowadays VR can be commonly found in a great variety of applications such as virtual modelling, ergonomic studies and, with higher intensity, VR is used on the entertainment industry to create games, movies and animations (Francis and Tan 1999). VR has become very useful for the development of 3D virtual environments for simulated exercises, as can be observed in several works, as observed in: Luna et al. (2012), which highlights the collaborative interactions between real humans and virtual humans in teamwork; Silva et al. (2015) have developed a virtual environment that simulates the structure of a nuclear installation, to assist on planning strategies, allowing an evaluation of the procedures performed, as well as assisting the training of security personnel in nuclear and radioactive facilities; Mol et al. (2013) proposed the use of virtual simulation through reusing a game engine platform in which people are able to navigate and interact among themselves, to support ergonomics evaluation of control rooms for licensing of nuclear power plants (NPPs) and many other surveys.

The great range of VR applications make possible to classify VR applications according to the way in which the user interact with the virtual environment. There are two classes: immersive VR (IVR) and non-immersive VR (NIVR) (Burdea and Coiffet 2003).

IVR intends 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. Therefore, special technologies are used to block up the user's perception. IVR also tries 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 (Haguenauer et al. 2011).

On the other hand, NIVR does not require the total isolation of the user. So, regular devices such as monitors, keyboards, mouse and others are used as it is observed at the application proposed in this work.

Although it is classified as non-immersive, the method proposed in this work tries to provide the user an immersive experience in order to give him a more realistic feeling when using the collaborative virtual environment (CVE) besides of contributing to improve the training procedure itself.

3 Collaborative systems

Collaborative systems are the ones that allow interaction between individuals and groups to perform tasks. They are used to designate the terms "groupware" and "CSCW" (computer-supported cooperative work). Groupware is defined by Ellis et al. (1991) as computational systems whose interface is able to offer a shared environment to support groups of people to engage in a task, thus encouraging the communication, collaboration and coordination between them. The big challenge of these applications occurs when the collaborative activity starts to occur in real time, and especially in collaborative virtual environments shared by users remotely located.

The collaboration provides not only the coordination of knowledge and individual efforts but also the interaction among people with complementary understandings, points of view and skills (Pimentel and Fucks 2011). The 3C model analyses the collaboration based on three parameters: communication, coordination and cooperation. Figure 1 presents a 3C model diagram based on Ellis et al. (1991).

The information exchanges occurring while communication takes place generate compromises that are managed by coordination, which provides the protocols and rules needed to organize the activities, then avoiding that communication and cooperative efforts be wasted by the individuals. The need to renegotiate and take decisions about unexpected situations during the cooperative processes requires more communication; this in turn demands coordination to reorganize the tasks. This shows the collaboration's cyclic aspect besides of the interdependence among communication, coordination and cooperation.

CVE's that support the 3C model, allow the user to use communication to align and refine group ideas, exchange information relevant to the training context, among others. With the coordination, the users can identify the progress of the work of the companions, such as what was done and what remains to be done, the progress of the tasks among others. In relation to cooperation, users share information about the perception of objects in the environment, such as the behaviour of avatars that anticipate actions and needs, as well as identify the intentions of group members.

4 Collaborative virtual environments

The ability of communicating and collaborating with each other to perform information exchange plays a very important role on human development. Considering the popularization of the computers and the rise of the internet, digital inclusion has become a reality even in poorest countries. Supported by the quick development of the virtual reality (VR), the collaborative virtual environment (CVE) is the evolution of the regular virtual environments intended to aid multiple users participating of a same interaction. Santos et al. (2002) have defined a CVE as a convergence point between VR research areas and collaborative systems (CSCW).

Concerning that, CVEs bring a new perspective to collaborative group work learning, as it provides the users interactions by means of simulations of the real world and manipulation of virtual objects as it is in the real world (Hagsand 1996). The use of a CVE stimulates the participation of the individuals by dynamically providing teaching activities, training, recreation and many others. In security applications, a CVE can connect remotely different research facilities and local command centres in order to perform trainings on procedures such as detection of hazardous materials and firefighting (XVR platform 2016) besides conflict management (Emmerich et al. 2012), training improvement (Correia et al. 2016), rescue training (Chen and Huadong 2006), support the physical security of nuclear facilities (Silva et al. 2015), for instance. Table 1 shows a comparison between the previously mentioned CVE's and the one presented in this work.

The use of CVEs allows the users to freely navigate inside the virtual space (spatial sharing) and they can interact with other users (presence sharing). Additionally, each of the users must be capable to observe the behaviour of the other ones in real time (time sharing) enhancing mutual situation awareness. In such environment, the

Fig. 1 3C model used in CVE

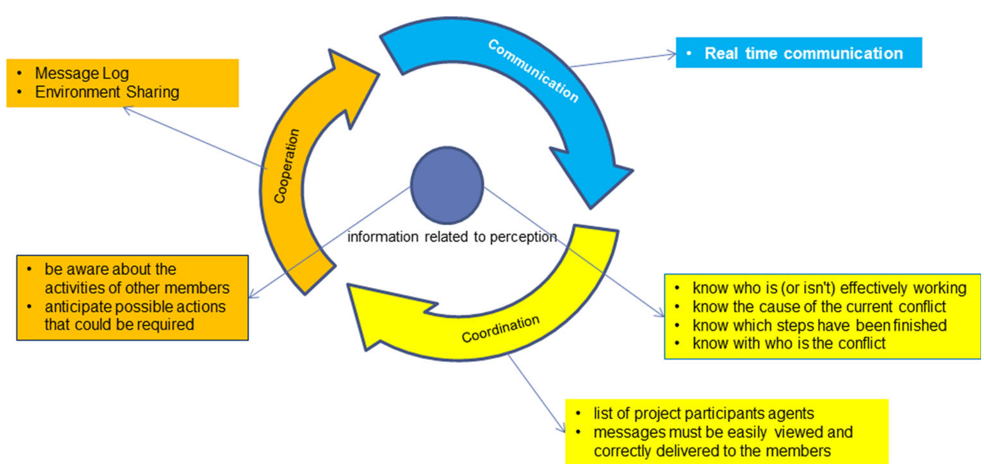

Table 1 Comparisons between CVE's

	CVE	Collaborative conflict management	XVR platform	A collaborative virtual simulation system based on HLA for emergency rescue training	Using virtual reality to support the physical security of nuclear facilities
3D virtual environments	x		x	x	x
2D virtual environments		x			
Non-verbal communications					
Verbal communications	x		x	x	
Chat	x	x	x	x	
Coordination	x	x	x	x	
Multiple users	x	Until 3	x	From 3 to 6	
Avatars	x		x	x	x
Awareness about order users actions	x		x	x	
Multi-platform	x				x
High performance Hardware			x		
Concerning the support physical security					
Multi-agency exercises	x		x		
Fireman (Fire and Rescue)			x	x	
Fireman (radiation)	x				
Police	x		x		
Ambulance			x		
CNEN agent	x				x

verbal and non-verbal communications inevitably occur, as well as coordination and cooperation characteristics. The verbal communication is generally performed by means of chatting tools and audio or video conference, whereas the non-verbal one comprehends gestures, facial expressions and avatar's posture. Communication in a CVE is commonly synchronous although it can be also asynchronous. Table 2 shows in compact form as features of CVEs can be associated with the main features of CSCW environments relating them (Pinho 2002).

5 Method

The work was divided into four stages of development: task analysis, case study for user interface design specification (UI), user interface prototyping and user evaluation.

In the analysis phase, interviews with CNEN agents and nuclear experts were conducted to identify the objectives, requirements and data sources that describe a nuclear threat situation, in order to define what information is needed for representation through the UI.

In the specification phase of the UI, a case study was developed to justify the knowledge through the UI.

In the prototyping phase of the UI, a representation of the interface is proposed using a graphical modelling tool (3Ds Max) and a game engine (Unity 3D).

And finally, the evaluation phase users that evaluate the level of user awareness in simulation scenario.

6 Cognitive task analysis

Data collection and analysis were performed with the support of cognitive task analysis (CTA) (Crandall et al. 2006). CTA provides a set of methods and tools to elicit knowledge, capture strategies and procedures, and identify cognitive skills. We interview CNEN agents who participated in the identification of radioactive materials during 2014 FIFA World Cup to and in Rio 2016 Olympic Games. These agents followed standard operational procedures during these events and they did not have a formal training before the events on how to perform their tasks.

The final product of the CTA analysis is a list of functional requirements that the CVE must have to support the development of skills needed to perform the task of radioactive material identification carried by people in big events. The basic user interface functional requirements were:

Table 2 Association between features of CSCW and CVE adapted from (Pinho 2002)

CSCW features	Identification in AVCs
Formation of groups	Can be made through navigation. The physical proximity between avatars supports the formation of groups
Negotiation support	The communication mechanism are the same as CSCW
Need for control of state transitions	The concept of 3D space and the possibility of communication between users will give support for transitions
Sharing the same understanding	The existence of the same 3D space provides the idea of sharing in an implicit way
Multiple views of the same information	Each user can see 3D objects (data) from different point of view
Awareness and perception of situation	The use of avatars allows a user to realize the existence of a partner, identifying it and understanding its activity

- working with more than one agent,
- working with more than one security agency (CNEN agents, firefighters, police),
- communication among agents,
- use of dosimeter for radiation detection,
- more than one suspect arriving together,
- radioactive material with doses different (from very low to very high level),
- ways to support training strategies to capture and arrest the suspect,
- ways to support training strategies to identify false possives (people who passed through radioactive-based therapy or examinations)
- ability to open and close passages in the virtual environment,
- possibility of walk and running represented in the CVE interface, as well as spatial and temporal aspects.

7 CVE design for security agents training

The CVE modelling comprehends characteristics as shape and appearance of objects, ambient lighting, input and output devices mapping and restrictions imposed when inside the simulation, all of which aid in the usability. The development of a CVE requires the use of different types of components including scenario, objects, avatars, animations, texts, videos and sounds. To give realism to it, the objects are designed in 3D according to its real counterparts.

The modelling also met the requirements important for CVE usability, such as quick updating of the scenes (ensuring the same scene for all users), user's visual perspective on avatar (in first or third person), use of familiar keys in environments of games and shortcut keys, use of the mouse to move and to perform actions, and use of joystick, real-time communication.

The method aims the developing a CVE and implementing its functionalities to reproduce a real situation where security agents can be trained to improve its skills when dealing with security issues. To exemplify the method, we develop a CVE representing Maracanã soccer stadium. The method comprises the following steps:

1. Modelling the environment where situation occur;
2. Avatars modelling;
3. Implementation of the environment and definition of available functionalities.

7.1 Environment modelling (Maracanã and its neighbourhoods)

The modelling of Maracanã stadium and its neighbourhoods was done by means of Autodesk 3Ds Max software. The process is started by adding a topographic image, which will be the reference for the modelled area. Figure 2 shows an image of Maracanã from Google Earth.

Poly-modelling is the technique used to modelling it, which consists on adding a primitive box to the virtual space. Next, the shape of the object was refined with textures and colours to provide more fidelity to the original stadium. Figures 3 and 4 show examples of these steps.

7.2 Terrain modelling

Unity 3D was used to perform the modelling of Maracanã's terrain. After having finished the modelling, the texture and modifications concerned the area's land relief were applied. Then the objects and edifications were inserted into the virtual environment. Such objects were imported from 3Ds Max to the terrain modelled at Unity 3D as shown in Fig. 5. Figure 6 shows the stadium entrance, where Bellini's statue is located, which is also present at the real stadium. This is to give to the users a major feeling of

Fig. 2 Image of Maracanã from Google Earth

immersion, once everyone who has already visited Maracanã will recognize it.

7.3 Avatars modelling

Avatars are used to provide interaction between the user and the developed environment. In this work besides of the generic avatars representing the audience, there are also specific avatars representing the security agents and suspects. Depending on the ongoing implementation, these avatars can act in different ways such as firefighters, police officers or agents from the local command and control centre, according to the user's will. In Brazil, the Comissão Nacional de Energia Nuclear—CNEN—is the Federal organization responsible for deal with problems related to nuclear issues. As we intend to perform simulations related to suspect carrying radioactive materials, we focus on CNEN agents training using the proposed CVE, although firefighters and police officers avatars actions are already implemented and available for the other type of scenarios and users. Figures 7 and 8 show the CNEN agent avatar modelling in 3D Max while Fig. 9 shows the avatar inserted into Unity interface.

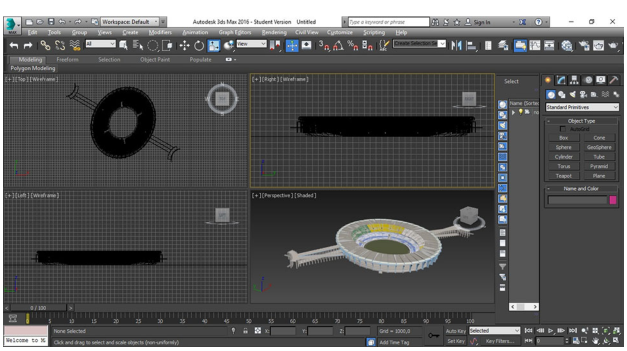

Fig. 3 Autodesk 3Ds max interface/Initial step

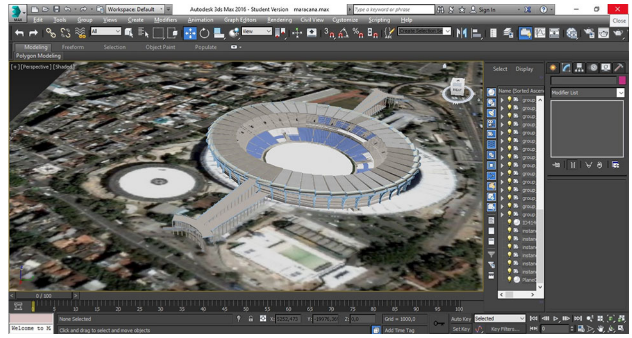

Fig. 4 Object's refinement step

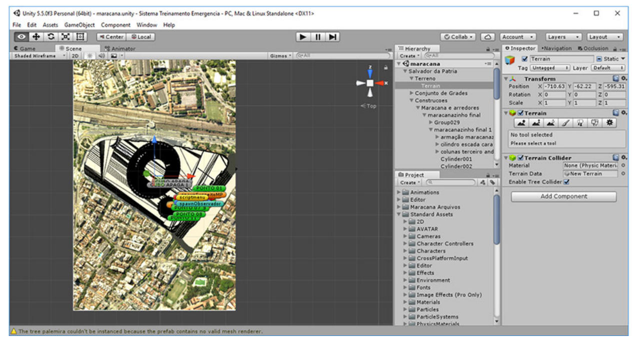

Fig. 5 Unity 3D interface

Fig. 6 Stadium model

7.4 CVE implementation and functionalities

There were implemented traditional animations to walk, run and jump, and also some necessary features for the training of agents. The actions of automata avatars were developed with algorithms based on artificial intelligence to simulate the spectators walking towards the stadium interior. This kind of avatar is randomly created at two locations set every two seconds, being deleted after they have reached the end of the ramp stage. The speed of

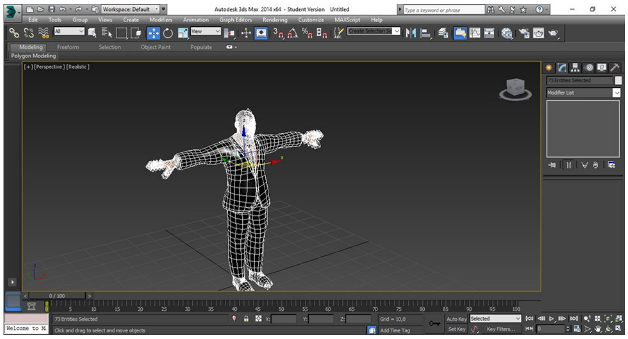

Fig. 7 Avatar mesh generation in 3D Max

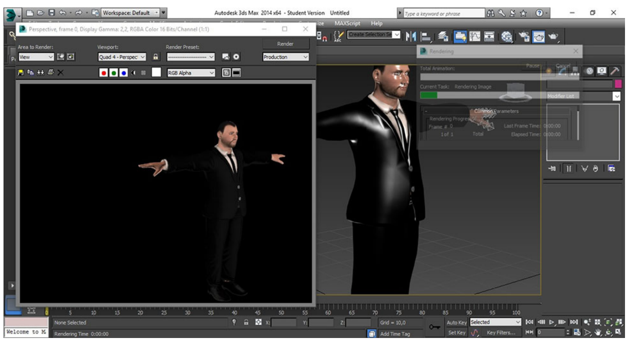

Fig. 8 Pre-rendered avatar in 3D Max

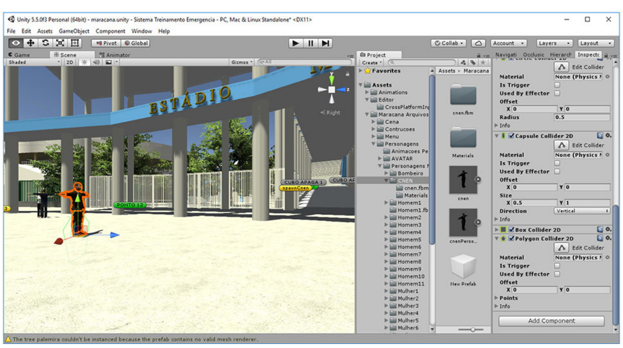

Fig. 9 Avatar inserted in unity

displacement of these avatars was adjusted to reflect the true velocity of a human being up both the ramp and around the stadium.

There are also controllable avatars which can represent both suspect(s) and security agents. The controlled avatars representing suspects can carry both high- and low-activity radioactive materials. The avatars representing security agents available in this CVE are: CNEN agent, policeman, fireman and watcher, a functionality that has information on all participants in the simulation. Table 3 shows so exemplified the functionalities present in the CVE for the training of agents, and Table 4 shows the functionalities of the suspect (s). The "watcher" is only a name for a function, not a character, i.e. the user controlling it will not act as an avatar during the simulation, being just a beholder of the other ones actions.

During the simulation, the user in charge of simulation can create avatars representing hostiles (then called "suspects") carrying the hazardous material just pressing F2. Each time this command is performed, a new suspect will be created. It is known as single user mode, very useful for individual training. There are also controlled avatars for representing suspects, which can provide a more realistic experience for the user of this application. Figure 10 shows the menu screen of the proposed application, where CNEN is the security agent; HR suspect and LR suspect are the hostiles carrying high- and low-activity radioactive materials, respectively; fireman and policeman are alternative applications of security agents, and watcher is a character who has information on all the participants of the simulation being responsible for coordinating the team actions (it has been not used in this work).

7.5 Usability of CVE

According to Nielsen (1993), usability is a quality attribute that assesses how easy user interfaces are to use. The word "usability" also refers to methods for improving ease of use during the design process.

An interface as a whole must present intuitiveness, efficiency, memorization, satisfaction, error handling, integrity, consistency and flexibility. Therefore, besides to these interface criteria, some ergonomic considerations were implemented in the proposed CVE to help the development of tasks that will be performed by users, such as:

- Simplicity—Since the commands for the execution of tasks are easy to use;
- Support—The user is always in control of actions;
- Familiarity—Input keys similar to those used in the gaming world.
- Awareness—Since built objects and their controls are always visible to the user.
- Availability—The user has access to great deal of the CVE objects and functionality at any time.
- Affinity—Scenario, objects and functionalities very close to the reality of agents.

8 CVE test

The simulation exercise was proposed to bring the CNEN agents closer to actual situations they will be facing, as well as to discuss some of the procedures used by them in

Table 3 Functionalities available to agents

Agents	Functionalities
	Measure radiation to identify suspects Address the suspects Communicate with agents of their own agency and other agencies
	Use the radiation detector Communicate with agents of their own agency and other agencies
	Arrest suspect Surround and evacuate area(s) with bars Organize queue (s) with bars Communicate with agents of their own agency and other agencies
Watcher (no avatar)	Select the camera of the agent that you want to watch Communicate with the agent (s) Correct wrong procedures Organize the whole staff

Table 4 Functionality available to suspects

	Transporting high-activity radioactive material or low-activity radioactive material Communicate with other(s) suspect(s)

activities. The exercise was carried out in the virtual reality laboratory of the IEN, which has the necessary infrastructure to carry out the simulations.

The scenario proposed for the exercise was a stadium (we model Maracanã). This was the initial message, which was complemented by other messages over time, as agents carry out actions related to the identification and capture of radioactive materials.

Were elaborated five scenarios that propose particular situations that require different strategies and collaborative aspects/competencies to capture the hostiles. The use of each of the available scenarios allows the users to enhance several competencies such as collaboration (scenarios 1, 2 and 3), communication (scenarios 1, 2 and 3), internal coordination (scenario 4), radioactive source identification

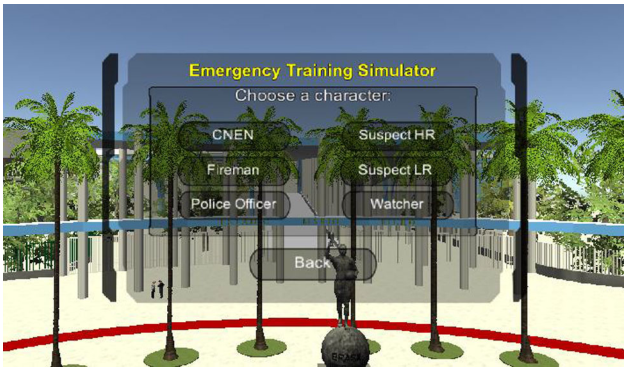

Fig. 10 Menu screen

(all scenarios) and field approach (all scenarios). The description of each scenario is shown in Table 5.

However, this approach has resulted in several cases of false positive during the games. For this reason, the agents have suggested that some specific abilities should be detached during the training using the CVE.

Based on this configuration, four simulation exercise sessions were performed, 6 simulations at the first session, 8 simulations at the second session, 6 simulations at the third session and 4 simulations at the fourth session. Considering scenario preparation, briefing, simulation and debriefing, each simulation lasted an average of thirty minutes.

Before the test, the agents discussed the procedures performed in the 2014 FIFA World Cup (for the first three sessions) and Rio 2016 Olympic Games (for the fourth session). In the beginning of the data collection process, the agents attended training classes that were part of the preparation for the exercise.

Additionally, we employed a non-participant observation technique for data collection during the test, resulting in notes used by the authors of the research to complement the analysis along with the audiovisual material generated in the simulation.

The four sessions had the direct participation of five people. Two CNEN agents have played as "agent" avatars in the two initial sessions. There were also three collaborators: one of them played as "agent" avatar (he received instructions of the CNEN agents to do so) while the other two have played as "suspect" avatars. The third session was attended by three agents and two collaborators in the role of suspect, while in the fourth session, three agents participated, being one agent in the role of police officer and two collaborators in the role of suspect. Each CNEN agent had a headset to communicate with each other.

9 CVE evaluation

The evaluation of CVE usability was based on the impressions of the CNEN agents who participate in the simulations. The evaluation questionnaire had questions about:

- previous experience;
- usability of CVE;
- degree of fidelity between the virtual environment and its real equivalent;
- use of CVE as security training tool;
- use of CVE as collaborative training tool;

Concerning the evaluation of the CVE as a collaborative tool, the agents answered questions related to communication, coordination and cooperation. It was considered questions regarding the degree of support that CVE provides for communication, such as verbal and/or textual communication and quality of communication. Coordination relation questions, on the other hand, approached the quality of available services, such as lists of agents' present, visualization of the tasks of these agents and access to the messages exchanged between them. Regarding the cooperation questions, they evaluated whether the environment allows the accomplishment of operations in a shared space for the execution of the tasks. A suggestion for future work would be the implementation of non-verbal communication through gestures performed by the avatars, which could help in both communication and coordination.

10 Data analysis procedures

First, the researchers transcribed what each CNEN agent had said in chronological order—into a single document file, guided by the audio captured. As a result of the transcription and analysis of data, other document file containing the sequence of the agents' actions, based on the audio captured and transcribed, was put together. Such material contributed to the representativeness of the data collected and the results obtained from the analysis. The material was held to provide comprehension of the activities, decision-making, collaboration and the main goals.

After the audiovisual content was transcribed, the researchers read excerpts and reports, and tried to find evidence of discrepancies between the actions carried out and the procedures. That material was used as a reference in a validation meeting with the agents who participated in the simulation, where were discussed each decision-making aspect that came out during data analysis.

Table 5 Scenarios descriptions

Scenario 1
At scenario 1, there is one suspect (controlled avatar) carrying a low-dose radioactive source. It aims to difficult its identification by the agents, because its detection will require that the dosimeter be in a major proximity of it. In addition, the suspect can hide among the other spectators (automata avatars). These characteristics are intended to stimulate communication between the agents
Objectives
Promote collaboration to effectively accomplish the mission
Keep informed the other agents about what is happening
Ensure integration with agents of other agencies
Provide a clear, concise, complete and correct verbal communication to the other agents participating in the training procedure
Promote the domain of the dosimeter use by agents
Scenario 2
At scenario 2, there is one suspect (controlled avatar) carrying a high-dose radioactive source. It aims to difficult its identification by the agents, because its detection can be done by the two agents at the same time, which could raise the chance of a false positive. As observed in scenario 1, the suspect can hide among the other spectators (automata avatars). These characteristics are intended to stimulate communication besides of improving their coordination
Objectives
Promote collaboration to effectively accomplish the mission
Keep informed the other agents about what is happening
Ensure integration with agents of other agencies
Provide a clear, concise, complete and correct verbal communication to the other agents participating in the event
Promote the domain of the dosimeter use by agents
Scenario 3
At scenario 3, there are two suspects (controlled avatars) each one carrying a low-dose radioactive source. With two suspects, there is a major chance of failure viewing that the number of agents was kept the same. At the simulated exercises, we have considered that if only one of them is identified, the result of the simulation is defined as failure, i.e. it is required that both being captured to achieve success. This scenario allows to promote the development of new strategies to both agents and suspects according to their particular objectives. As observed in scenarios 1 and 2, the suspects can also hide among the other spectators (automata avatars) which contribute to increase the difficult on finding them. These characteristics are intended to stimulate communication besides of improving their coordination and cooperation
Objectives
Promote collaboration, coordination and cooperation to effectively accomplish the mission
Keep informed the other agents about what is happening
Ensure integration with agents of other agencies
Provide a clear, concise, complete and correct verbal communication to the other agents participating in the event
Promote the domain of the dosimeter use by agents
Scenario 4
Scenario 4 describes a hypothetical situation where failure is the only possible result. In face of that, they must to coordinate among themselves to define new identification strategies, such as new ways of positioning and displacement
Objective
Provide coordination between agents and new strategies of the identification
Scenario 5
Scenario 5 is intended to improve the use of the dosimeter by agents without exposing them to radiological risks
Objective
Promote the domain of the dosimeter use by agents

11 Results

The same procedure used during 2014 FIFA World Cup Brazil™ to detect radioactive materials was used to perform the three simulation sessions. The tests comprehend an amount of 20 simulations with 6 simulations at the first session, 8 simulations at the second session and 6 simulations at the third session (they are described in Table 5). The results of sessions 1, 2 and 3 are presented in Tables 6, 7 and 8, respectively.

In the first two sessions, the team was composed by two professionals of CNEN that have worked at the security crew during 2014 FIFA World Cup Brazil™ which have controlled the virtual versions of the security agents, besides three volunteers responsible for controlling the other avatars (one of them, controlling the third agent while the last two, controlled the suspects).

The third session had the participation of a third professional which, as well as the other two, who were in the previous sessions, also had worked in the World Cup in Brazil in 2014 and the Rio 2016 Olympic Games. Each of them has more than 15 years of experience on dealing with radioactive safety, which qualifies them to provide a reliable evaluation about the proposed CVE, thus contributing to highlight its positive and negative characteristics.

Regardless of the low domain of the agents and collaborators related to the use of the CVE, its assessment was very satisfactory. The graph in Fig. 11 shows the feedback provided by them at the end of the training simulations.

11.1 Discussion

As observed in Table 6, there were three simulations (namely 1, 2 and 3) concerning scenario 1 and other three simulations (namely 4, 5 and 6) concerning scenario 2. Simulations 1 and 2 have result in fail as the suspect managed to run way from the security agents. At simulation 3, the agents were able to correctly identify the suspect. The fail observed in simulations 1 and 2 was due to the absence of collaboration among the agents. As observed in simulation 3, the communications among them have helped on the correct identification of the suspect.

At the simulations referred to scenario 2, similar results were observed, despite the fact that all of them have resulted in success. In this first session, the results have shown that only when the agents worked together the success was achieved, which detaches the major role played by collaboration in such situations. At the end of session 1, the CNEN agents have suggested some changes that could improve the experience of the user. After having implementing it, they were invited for a new session of experiments that compound session 2 simulations.

The changes suggested by the agents as well as the results obtained at the end of session 2 are shown in Table 7. There were three simulations (namely 1, 2 and 3) concerning scenario 1, one simulation concerning scenario 2 (namely 4) and other four simulations (namely 5, 6, 7 and 8) concerning scenario 3. All the simulations referred to scenario 1 have resulted in success.

There was a correct identification of the suspect also at scenario 2. However, the agents have felt uncomfortable using the joystick and the first person view (which were suggested by them at the end of the session 1). Therefore, the remaining tests were performed according to the specifications used in session 1 simulations (except for simulation 8, in which they have used first person view). Again, the agents were able to identify the "suspect" avatar correctly at simulations 6, 7 and 8. Simulation 5 was defined as "Fail" because just one of the suspects was identified.

Considering that the agents who participated in the previous sessions would work in the radiological safety of the Rio 2016 Olympic Games, the interval between the second and third session had to be higher compared to the first two. It was then composed of six (6) simulations, among which only half corresponded to success in the correct identification of suspects, as shown in Table 8. This result reflected the degree of difficulty presented in scenario 3, whose simulations involved 2 (two) suspects. While one of them attracted the attention of the agent, the other tried to overcome the barrier. Since the dosimeter cannot distinguish the radioactive activity of more than one source at a time, it contributed to a major number of failures.

According to the reports of the experts involved, the procedure for identification of suspects used during the World Cup in 2014 was inadequate, which is confirmed by several failures and false positives, and a new procedure to avoid that the same problem occurs was developed for the Rio 2016 Olympic Games. This new approaching had to be performed as follows: as soon as an agent detected the presence of radioactivity, the national security force was contacted to block the passage of all people, until the hazardous material (in this case a nuclear source) be found.

Table 6 Results for the first session of tests

Simulation	Scenario	Result	Barrier of identification	Collaboration			Control of avatars	User view
				Communication	Coordination	Cooperation		
1	1	Fail	–	No	No	No	Keyboard and mouse	3ª Person
2	1	Fail	–	No	No	No	Keyboard and mouse	3ª Person
3	1	Success	Second Barrier	Yes	No	Yes	Keyboard and mouse	3ª Person
4	2	Success	First Barrier	No	No	No	Keyboard and mouse	3ª Person
5	2	Success	First Barrier	No	No	No	Keyboard and mouse	3ª Person
6	2	Success	Second barrier	Yes	No	Yes	Keyboard and mouse	3ª Person

Table 7 Results for the second session of tests

Simulation	Scenario	Result	Barrier of identification	Collaboration			Control of avatars	User view
				Communication	Coordination	Cooperation		
1	1	Success	First Barrier	No	No	No	Joystick	1ª Person
2	1	Success	Second Barrier	Yes	No	Yes	Joystick	1ª Person
3	1	Success	First Barrier	Yes	No	Yes	Joystick	3ª Person
4	2	Success	First Barrier	No	No	No	Keyboard and mouse	1ª Person
5	3	Fail	–	Yes	No	Yes	Keyboard and mouse	3ª Person
6	3	Success	Second Barrier	Yes	No	Yes	Keyboard and mouse	3ª Person
7	3	Success	First Barrier	Yes	No	Yes	Keyboard and mouse	3ª Person
8	3	Success	First Barrier	Yes	No	Yes	Keyboard and mouse	1ª Person

Table 8 Results for the third session of tests

Simulation	Scenario	Result	Barrier of identification	Collaboration			Control of avatars	User view
				Communication	Coordination	Cooperation		
1	1	Success	First Barrier	No	No	No	Keyboard and mouse	3ª Person
2	3	Fail	First Barrier (only one of the suspects)	Yes	No	Yes	Keyboard and mouse	3ª Person
3	3	Fail	First Barrier (only one of the suspects)	Yes	No	Yes	Keyboard and mouse	3ª Person
4	3	Success	First Barrier (the two suspects)	Yes	No	Yes	Keyboard and mouse	3ª Person
5	3	Fail	First Barrier (only one of the suspects)	Yes	No	Yes	Keyboard and mouse	3ª Person
6	3	Success	First and Second Barrier	Yes	Yes	Yes	Keyboard and mouse	3ª Person

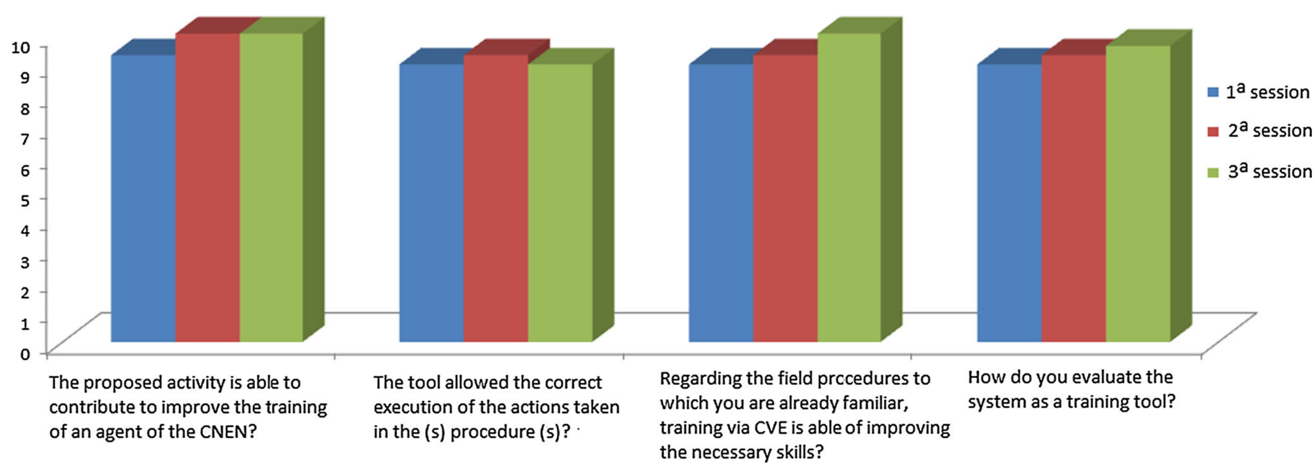

Fig. 11 Comparative graph concerning the use of simulation as a training tool

Table 9 Results for the fourth session of tests

Simulation	Result	Collaboration			Control of avatars	User view
		Communication	Coordination	Cooperation		
1	Success	Yes	Yes	Yes	Keyboard and mouse	3ª Parson
2	Success	Yes	Yes	Yes	Keyboard and mouse	3ª Parson
3	Success	Yes	Yes	Yes	Keyboard and mouse	3ª Parson
4	Success	Yes	Yes	Yes	Keyboard and mouse	3ª Parson

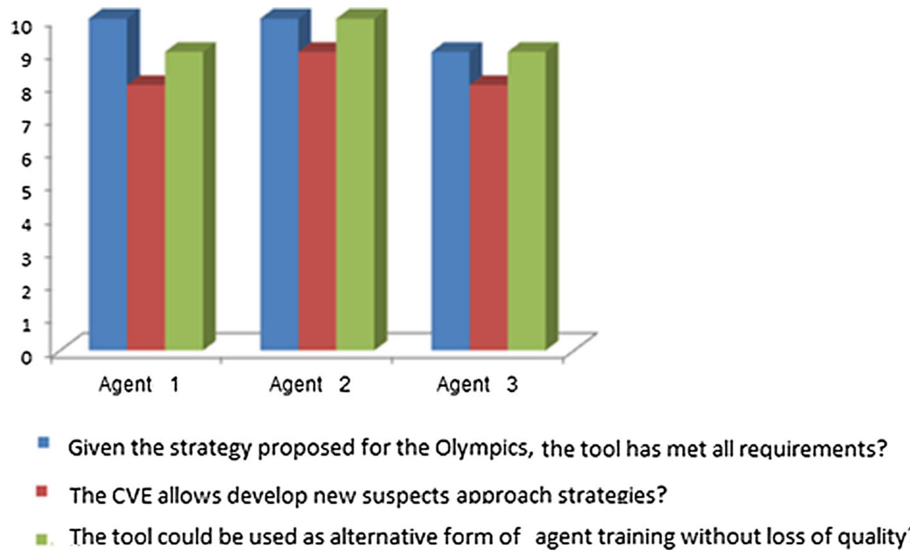

Fig. 12 Graph regarding the use of the virtual environment as a tool for new training strategies

The scenarios proposed in the simulations described above allowed to reproduce the original procedure faithfully, with results quite similar to the ones observed in the field. Based on the description of the new approach used for the Rio 2016 Olympic Games, a new scenario using the CVE was prepared, aiming to reproduce it. Thus, the aim of this new simulation is to evaluate the suitability of the proposed CVE as an alternative tool for developing new strategies of suspect identification.

Given that, a fourth session was planned, with four simulations related to the context of scenario 3. According to the results shown in Table 9, the identifying procedure was successfully performed in all simulations of this fourth session. The graph of Fig. 12 presents how the agents evaluated the proposed CVE concerning its suitability for the development of new strategies.

12 Conclusions

The collaborative virtual environment (CVE) proposed in this work has managed to reproduce the real training action scenario with a great degree of interactivity and immersion, transferring the user (here represented by CNEN agents with field experience in identification of hazardous materials) to an interactive three-dimensional virtual environment. In such environment, the agents, using avatars, are capable to make decisions and develop collaborative actions, which contribute to promote an additional value for the training procedures. Regarding usability, the interaction resources presented both control and visualization showed efficient to operationalize the tasks, helping a lot in the effectiveness of the results. So, the CVE described here has proved to be suitable for training simulations viewing that it was able to represent scenarios quite similar to its real counterparts referring to abnormal situations in big events as the ones experienced by CNEN agents during the FIFA 2014 World Cup and Rio 2016 Olympic Games.

Furthermore, as confirmed by experienced professionals, the proposed method can effectively contribute to improve skills such as team organization and leadership, improve the skills of agents, as well as possible to assess the level of collaboration of the team through coordination, communication and cooperation among team members. It was also observed that the participants had no difficulty to operate when acting together inside the CVE.

They highlighted, among other important aspects, the possibility to have a variable number of agents (including other agencies such as firefighters and police officers). Among the main functions available in CVE proposed in this thesis highlighted by experts agents are:

- capture (the suspect/criminal);
- release (the suspect when setting the error in the identification of it);
- closing gates (which helps to limit the scanning area to identify a suspect);
- using dosimeters (which have the same functions available in your real equivalent as radioactivity counter and audible signal to guide the identification of a radioactive source);
- putting mobile grids (in order to organize queues, corridors, isolate areas or create surrounded).

All these features, combined with the possibility of communication between users, qualify the proposed method as a promising tool to aid in the creation of new training strategies, avoiding losses with the displacement of people and the availability of specific places to the completion of training in addition to having the advantage of not subjecting agents to the risks of exposure to hazardous materials. The tool also provides the function "watcher" (not used in any of the scenarios described above) which can act only as a beholder or as a coordinator of the teams. Finally, it is important to emphasize that all of the implemented functionalities can be used in several other contexts and/or be expanded to other scenarios and/or training procedures, which makes it versatile and adaptable tool.

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