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An Immersive Serious Game for Firefighting and Evacuation Training in Healthcare Facilities

Anass Rahouti, Guillaume Salze, Ruggiero Lovreglio, Sélim Datoussaïd

***Abstract*—**In healthcare facilities, training the staff for firefighting and evacuation in real buildings is very challenging due to the presence of a vulnerable population in such an environment. In a standard environment, traditional approaches, such as fire drills, are often used to train the occupants and provide them with information about fire safety procedures. However, those traditional approaches may be inappropriate for a vulnerable population and can be inefficient from an educational viewpoint as it is impossible to expose the occupants to scenarios similar to a real emergency. Immersive serious games could be used as an alternative to traditional approaches to overcome their limitations. Serious games are already being used in different safety domains such as fires, earthquakes and terror attacks for several building types (e.g., office buildings, train stations, tunnels, etc.). In this study, we developed an immersive serious game to improve the fire safety skills of staff in healthcare facilities. An accurate representation of the healthcare environment was built in Unity3D by including visual and audio stimuli inspired from those employed in commercial action games. The serious game is organised in three levels. In each of them, the trainee is presented with a specific fire emergency and s/he can perform protective actions (e.g., firefighting, helping non-ambulant occupants, etc.) or s/he can ignore the opportunity for action and continue the evacuation. In this paper, we describe all the steps required to develop such a prototype, as well as the key questions that need to be answered, to develop a serious game for firefighting and evacuation in healthcare facilities.

***Keywords*—**Fire Safety, healthcare, serious game, training.

I. Introduction

PREPARING healthcare facility staff members for a fire event is challenging for educators utilizing traditional approaches. Fire drills can be used for teaching the staff members about fire safety procedures; however, those drills can easily fail from a pedagogical viewpoint [1]. Carrying out a fire drill in a healthcare environment requires significant logistical challenges, both with supplies and personnel [2], [3]. In addition, the presence of vulnerable occupants in such environments adds further challenges in terms of fire safety training [2], [3]. Furthermore, evacuation drills are generally costly, disruptive, and there is also little evidence of their effectiveness in improving the preparedness of an organization, or the quality of the emergency response [4]. Moreover, fire drills in a healthcare environment can be prohibited in some countries as they could expose the vulnerable occupants to a real threat [2]-[10]. Serious games might be an efficient alternative to traditional approaches to successfully teach the principles of fire safety using limited economic resources [3], [4], [9]. In this paper, we propose an immersive serious game to train the staff members on firefighting and evacuation procedures in healthcare environments.

The paper is organised as follows: In Section II, we present previous work on educational serious games as well as the advantages and limitations of serious games. Section III describes in detail the developed serious game. Section IV gives details about its implementation. Finally, Section V concludes the paper and provides guidelines for future developments of the proposed prototype.

II. Background

Serious games are video games with training and educational objectives [3], [5], [16]. They can enable players to learn via experiencing emergency situations. The concept of serious games is not new and has been used in the past in different safety domains (e.g., fires [5], [6], [12]-[16], earthquakes [4], [11] and terror attacks [16]) and, for several building types (e.g., hospitals [3], office buildings [13], tunnels [14] and train stations [16]). However, these studies only focused on evacuation training.

In [3], the concept of serious games has been explored as an important asset to aid and improve traditional fire drills in complex environments like hospitals. Unlike in our study, a hypothetical healthcare facility was modelled. This study has demonstrated that serious games can be used as an important instrument for behaviour elicitation.

As pointed out by Foronda et al. [4], immersive serious games hold a bright future as a pedagogy tool for current and future generations of nurses. In this study, an immersive serious game has been developed to prepare nursing students to triage effectively in a disaster situation (e.g., earthquake).

A serious game was proposed by Chittaro et al. [16] to simulate a mass emergency caused by a terror attack in a train station. They compared an interactive version of the game with a non-interactive version. They observed that both versions of the game can provide positive outcomes in learning, risk severity perception, and self-efficacy. However, they differ in how much they affect player's threat appraisal and emotional response.

A. Rahouti is with the Civil Engineering and Structural Mechanics Department, University of Mons, Mons, 7000, Belgium (corresponding author, phone: +3265374524; fax: +3265374528; e-mail: anass.rahouti@umons.ac.be).

G. Salze is with École nationale des mines d'Alès, 30100, Alès, France (e-mail: guillaume.salze@orange.fr).

R. Lovreglio is with the Civil and Environmental Engineering Department, University of Auckland, Auckland, NZ (e-mail: r.lovreglio@auckland.ac.nz).

S. Datoussaïd is with the Civil Engineering and Structural Mechanics Department, University of Mons, Mons, 7000, Belgium (e-mail: selim.datoussaid@umons.ac.be).

A commonality from previous studies is that serious games have the potential to be a powerful educational tool and to offer a wide range of advantages compared to traditional learning approaches. For example, serious games increase the realism of the learning experience and create engagement into the training. Indeed, features such as fire and smoke effects can easily be included in the virtual world without exposing trainees to any risk. Playing a game can be fun and engaging for users who would thus play the game whenever they want and from wherever they want. This could increase exposure time to personal fire safety content, and promote repetitive rehearsal of safety procedures, which improves retention of knowledge [16]. Unlike evacuation drills, a serious game would not disrupt the activity of the hospital and different situations can be designed with specific learning outcomes. Another advantage of serious games is that players' decisions can be assessed and every learner can have results on each predefined analysis criterion, with customised feedback.

Despite the advantages offered by serious games, there are also some limitations. A potential limitation is that trainees are not interacting with an actual physical environment, but instead might interact with the virtual world in artificial ways (e.g. using game controllers). In addition, it might be difficult to adequately represent stimuli for all human senses in serious games.

III. The Immersive Serious Game

In this section, we first illustrate the main design choices, and then we describe the game storylines.

A. Design Choices

The serious game was developed with a central goal to improve the fire safety skills of healthcare staff members. Through our serious game, they can realistically experience firefighting and fire evacuations of different severities and learn from the outcomes of taking different possible actions. To create an immersive experience, we used a first-person view and we carefully reproduced the 3D geometry of the 6th floor of a Belgian hospital; one of the most critical floors of this building [11], including common hospital furniture such as beds, wheelchairs, trolleys, etc. (Fig. 1). We included phenomena and objects directly related with fire emergency and evacuations. For example, fire and smoke effects, emergency exits, emergency signage, alarm triggers, fire extinguishers, as well as related sounds, such as alarms were used. Some of the game objects are interactive, i.e., they can be picked up or used depending on their type.

Fig. 1 First-person view showing a typical hospital single room

The proposed serious game allows players to become familiar with all the details of the R.A.C.E. (Remove, Alarm, Contain and Extinguish) and P.A.S.S. (Pull, Aim, Squeeze, Sweep) procedures. These procedures have been taken from publicly available healthcare facilities emergency guides [17], [18]. Our game is called "Prepare for Fire Emergency" and it is organised into three levels. Each level has specific learning objectives.

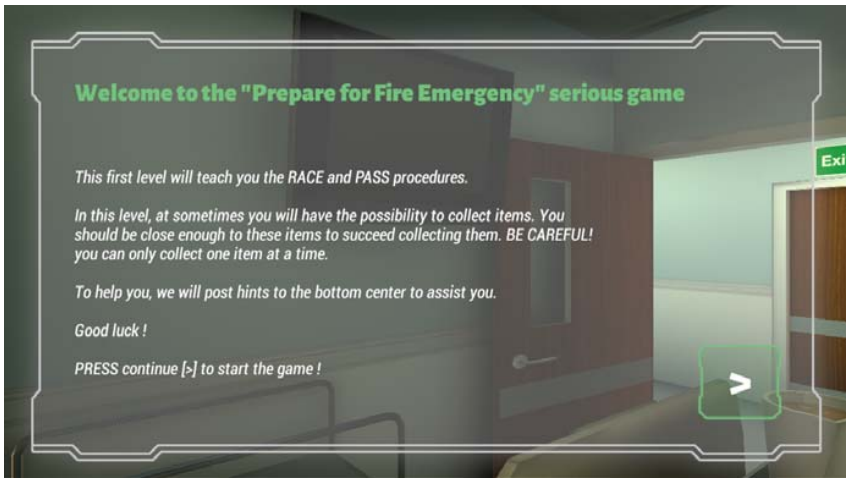

Fig. 2 Introduction panel of the first level

Learners start the exercise by choosing one of the three available levels. At the beginning of each level, a message indicates the objectives of the level (Fig. 2). The players are then presented with a specific fire emergency and their goal could be to extinguish the fire or to evacuate the floor. They have the possibility to follow emergency signs, and they need

to perform recommended actions [13] (e.g., call the fire brigade (Fig. 3), contain the fire (Fig. 4), help non-ambulant patients (Figs. 5 and 6), trigger the alarm (Fig. 7)). At the same time, they must avoid non-recommended actions [13] (e.g., taking an elevator, inhaling smoke, collecting objects such as documents during the evacuation phase, not respecting the prioritisation order of the non-ambulant patients, etc.).

Fig. 3 Cell phone to call the fire brigade

Fig. 4 Open and close doors

Fig. 5 Player assisting a non-ambulant patient using a wheelchair

To make the game accessible to novice players, we did not assume previous experience with video game controllers. All actions can be taken using the keyboard and mouse. The player controls the avatar (their game character) by using the mouse to orient the field of view and the arrow keys to control the movement. For actions aimed at collecting objects (documents (Fig. 8), fire extinguisher (Fig. 9), etc.), a button appears in the middle right of the screen to inform the player about currently available actions. The player can perform the action by pressing the appeared button. To activate the alarm or call the fire brigade, the player had to position the cross in the center of the screen over the alarm trigger (Fig. 7) or the cell phone (Fig. 3).

When a dangerous action is taken, the avatar dies. A game over screen appears including the reason for their death, and a recommendation that must be followed to avert the threat or to reduce its impact on the avatar's health (Fig. 10). The player then has the possibility to replay the level (Fig. 10).

Fig. 6 Player assisting a non-ambulant patient using a bed

Fig. 7 Alarm trigger

The full cause-of-death messages and recommendations we used are:

- When trainees die of toxic smoke inhalation or by fire threat, the cause of death message is "You died because you were too close to the fire or you inhaled smoke and toxic gas", whereas the recommendation is "Be careful of fire, smoke and toxic gas. If a fire is discovered and there is too much smoke, walk away from the fire and smoke, and keep low (30 to 60 cm from the ground)".
- When trainees open a hot door, the cause of death message is "The reason of your death is that you have opened a hot door", whereas the recommendation is "If a door is hot to the touch, you must not open it".
- When trainees did not check the situation as soon as possible, the cause of death message is "You didn't follow the instruction indicating to check the fire room

door as soon as possible" whereas the recommendation is "In a fire, every second is important. You should check the situation as soon as possible".

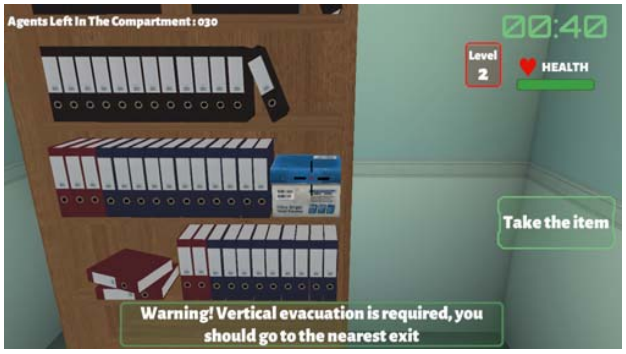

Fig. 8 Button showing the possible action (Collect important document) when the player is close enough to the document

Fig. 9 Button showing the possible action (take the fire extinguisher) when the player is close enough to a fire extinguisher

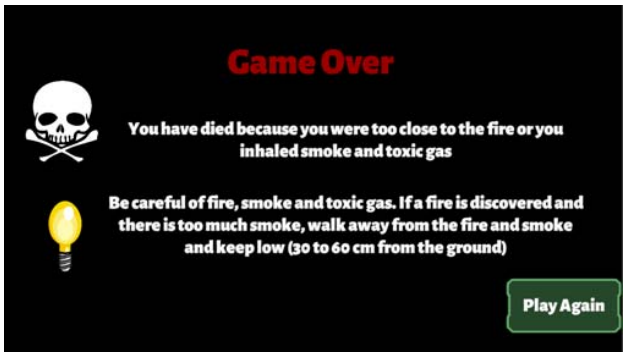

Fig. 10 A game over panel showing the cause-of-death message and the accompanied recommendation for fire and smoke threats as well as the "Play Again" button

The illustration of the outcomes of each level is completed by providing players with a debriefing panel (Fig. 11) that shows the correct and incorrect actions taken by the player. Wrong actions are highlighted in red. To each missed goal, we associated a penalty time (depending on its importance in the particular situation) which is added to the play time which forms the global time score for the level. There is also an implicit incentive to retry the game to see if you can do better next time. A prominent "Play Again" button allows players to conveniently replay the level and a "Continue" button allows players to return to the game's main menu.

The game includes visual and audio stimuli inspired from those employed in commercial action games. More specifically:

- When the trainee comes into contact with smoke, coughing sounds are played, and a dark vignette is shown in the screen (Fig. 12).
- When the trainee opens a hot door, the screen flashes in white for a fraction of a second, and tinnitus sound is played.
- When the trainee comes into contact with fire, a red vignette is shown on screen, and the sound of a human voice, screaming in pain, is played.
- During the normal activity of the hospital (i.e., before the sirens start ringing), the player can hear voices of people talking when navigating in the building.
- The player can also hear voices of wounded people in pain.
- A life bar is always shown on the top right of the screen to indicate player's health and possibly make trainees more aware of the severity of the threat (Fig. 12). When the player is healthy, the bar is completely green; every time the avatar is injured, health decreases, i.e., part of the bar becomes red, starting from the right side; when the bar is completely red, the player dies. When the player comes into contact with smoke or fire, health decreases constantly.
- A timer is always shown on the top right of the screen to indicate the time elapsed from the beginning of the level (Fig. 12).
- When the player takes an extinguisher, a slider appears in the left bottom of the player's view to show her/him the tank volume of the carried extinguisher (Fig. 12).
- When the player is facing a fire, a slider appears in the right bottom of the player's view to show her/him the size of the fire (Fig. 12).

B. Game Storylines

One of the actions that healthcare facilities personnel must deal with in fire emergency situations is to fight the fire if it is safe to do so [17], [18]. The first level is devoted to this action. The trainee starts this level in a single patient room (position A in Fig. 13) and tries to fulfil the assigned goals following the posted hints on the bottom center of the player's view. For example, at the beginning of the first level, s/he is invited to reach the room number 652 (position B in Fig. 13). Once s/he reached this room, after 5 seconds the alarm starts ringing and the player is asked to check the situation or to evacuate. If s/he decides to evacuate, the level ends once the player reached a safe place (e.g. an emergency exit). If s/he decides to reach the room in which a fire started, they face a small fire and must contain the fire (by closing the door of that room). They can then decide to search for a fire extinguisher to start fighting the fire or to evacuate. If they carried a fire extinguisher, they can then follow the P.A.S.S. procedure to

extinguish the fire. Once the fire is successfully extinguished, the level ends.

Fig. 11 Debriefing panel showing the correct and wrong actions as well as the penalty time associated with the wrong actions and the actual play time

Fig. 12 Fire and smoke threats

The second level starts in a corridor (position D in Fig. 13) and the avatar is facing a closed room in fire. S/he must check the situation. Once they are close enough to that room, they can decide whether or not to open the fire door and check the situation (the player is informed that the door seems to be hot to the touch). If they decide to open the door, they die and are informed of the reason of their death. They are then given a recommendation on the correct action to follow in this situation. And they can also replay the game. If s/he does not open the door, they can continue the level and activate the alarm simply by looking at an alarm trigger. The players can also call the fire brigade using the cell phone placed in their office (position F in Fig. 13). In that office, we displayed some collectable objects (e.g., important files) and the player can decide whether or not to take them with her/him when they evacuate the floor. If the player did not trigger the alarm and did not call the fire brigade after 1 minute of the play time, both actions are done by another occupant. If the player reaches the elevators, they can decide whether to take the lifts to evacuate. The level ends once the player reaches a safe place.

The last level also starts in a corridor (position G in Fig. 13). In this scenario, the alarm has already been activated. The player can see the storage premise on fire and must assist non-ambulant patients situated close to that premise (position H in Fig. 13) or start the evacuation. Once the player reaches the room where the patients requiring assistance are present, s/he faces two non-ambulant patients, one in a wheelchair and another in a bed. The player must decide the order of prioritisation of those patients and then drive the selected assisted patient to a safe place.

IV. Development

The hospital floor 3D geometry has been built from a CAD plan ("dwg" format) and real world data (taking pictures at the hospital) in Unity3D, a game engine used worldwide for the

development of video games.

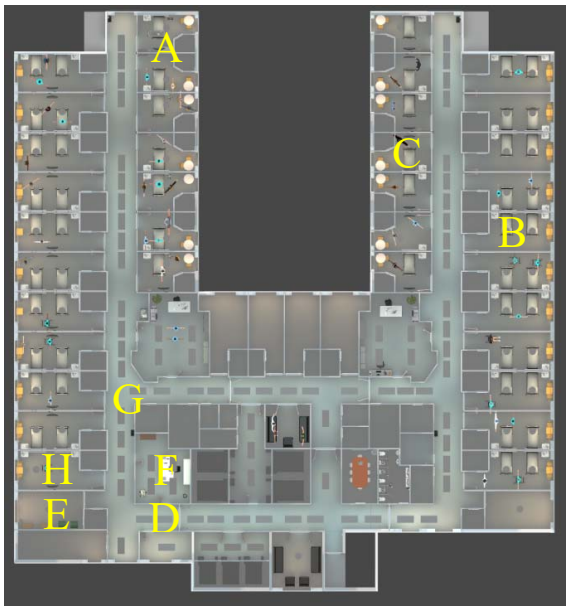

Fig. 13 Floor layout

The virtual characters (player and non-player characters (NPCs)) populating the virtual hospital floor have been modelled in Adobe Fuse CC software and then have been imported into Unity3D.

The furniture was imported from the asset store of Unity3D. We have arranged all objects in the environment and defined their interactive behaviours through C# code scripts. For instance, we placed a set of imperceptible triggers in the virtual world to analyse whether the player has taken an optimal route to the extinguisher or emergency exit [13]. NPCs behave following data on human behaviour in fire situations. Qualitative data (Behavioural statements) and quantitative data (e.g., walking speeds) have been taken from existing literature [2], [19], [20]. In hospitals, assisted evacuation is common during fire evacuations; therefore, an assisted evacuation sub-model has been developed to allow able-bodied NPCs to help non-ambulant patients [21].

Fire and smoke threats have been visually modelled by using billboards, animated textures, and particle systems, which are all features of Unity3D. To model the effect of fire and smoke on the player's health, we used invisible boxes. Whenever the player touches those boxes, their health bar decreases constantly [13].

V. Conclusions & Outlooks

In this paper, we propose the use of a serious game approach to educate healthcare facilities personnel in fire safety procedures. The developed serious game allows trainees to acquire the navigational knowledge required to leave their building safely [13], but also allows them to learn and practice, in a variety of different situations, and with some of the actions that are required in fire emergencies such as firefighting and triage of non-ambulant patients.

The game was developed in the Unity3D game engine; however, this game engine was not used to its full capability. To improve the developed prototype, future versions of this serious game will include more levels, will offer the possibility to users to personalise their avatars before starting the game (i.e., choose the gender, age, role, etc.). Furthermore, we will focus more on gaming elements related to users' coping appraisal such as improving the presentation of the recommendations.

In the presented prototype, panels for brief recommendations are used during the game. This feature has the possibility of decreasing the realism of the immersion. Other techniques that do not interrupt the game will be evaluated, such as the use of an NPC that accompanies players during the game and can help them by providing recommendations. Physically realistic simulations of smoke and fire spread (e.g., using the Fire Dynamics Simulator [22]) could also greatly improve the fidelity of the game to make it closer to a real fire emergency. We will also make the player more aware of the physiological state of their avatar (e.g., injuries) and the environment (e.g., heat, highly toxic gas) in the game.

People demonstrate better learning outcomes when they work collaboratively compared with individually [4]. Therefore, we intend to develop a multi-player version of the game to promote collaborative learning, possibly replacing some NPCs with other players. In this way, players who have a greater experience with videogames can help novice users, and players with similar experience levels can collaborate in dealing with threats presented by the game. Moreover, the multi-player serious game could consider different roles for the players (e.g., doctors, nurses, patients, visitors, etc.) and may be used to collect data on social and collaborative behaviours.

We will also provide players with the possibility to use virtual reality (using Head Mounted Displays) to increase the realism of the experience as well as microphones to talk in the multi-player version. In addition, an innovative feature of this multi-player game could be a unique scoring system that tracks players' actions and could identify a virtual winner. This competition may serve as a motivator for players.

Another future objective is to carry out tests with a sample of healthcare facilities personnel. We also intend to include some performance measures to study individual and crowd behaviours.

Finally, to evaluate if the players acquire and retain the knowledge provided by the game, we would like to employ a quiz game to evaluate the fire safety skills of players before and following the game.

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