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An advanced solutions for operators' training working in confined and /or pollution suspected space

L.Di Donato[a*], F. Longo[b], A. Ferraro[a], M. Pirozzi[a]

[a] *Inail, Via R. Ferruzzi 38, 38/40 - 00143 Roma, Italy*
[b] *DIMEG, University of Calabria, Via P. Bucci, Cube 45C, third floor*

* Corresponding author. *E-mail address:* l.didonato@inail.it

Abstract

Carrying out maintenance, regulation, installation of mechanical parts, cleaning and other activities in confined and / or suspected pollution spaces, often represents a challenge; indeed many are the cases of fatal incidents for operators. As in every country, there are ad-hoc regulations to increase the safety of operators at work: as far as Italy is concerned, the decree 177/2011 requires the qualification of companies operating in confined and / or suspected of pollution spaces with the aim of raising the level of safety, also defining strict criteria for all those business contracts related to confined spaces. However, while regulations clearly define what confined spaces are, the training issues are not appropriately addressed (e.g. the Italian legislation only makes reminder to general laws such as the decree 81/2008) and there is no uniformity in terms of methods, procedures and required training times for operators working in confined spaces.
The Italian National Institute for Insurance against Accidents at Work (INAIL) has conceptualized and developed a physical simulator for training those operators working in confined spaces. The research activities carried out by using the physical simulator points out that the integration of Industry 4.0 enabling technologies (such as Virtual and Augmented Reality developed in cooperation with University of Calabria) may further extend the training capabilities and operators' skills. The idea proposed in this article is to show how live exercises made with a physical simulator combined with Virtual Immersive and Interactive Reality can be profitably used to tackle the operators' training problem within confined spaces.

Keywords: Confined Spaces, Advanced Training, Virtual Reality, Industry 4.0

1. Introduction

Workers involved in complex operations (such as operations executed in confined space) are subjected not only to high risks but also to time pressure and to uncomfortable environments [1]. Those operators requires ad-hoc training to operate safely and effective not only in "stand-alone mode", but also when they are asked to interact and communicate with other team members [2]. In many sectors, the importance of live exercise and ad-hoc training has been widely recognized [3] as well as the importance of devising up-to-date and cost-effective adaptive training [4] and related performance measures [5]. At the same time, simulation and virtual environments are considered powerful training tools since the '90s [6] and simulation enabled learning has strongly overpassed traditional approaches in classrooms [7-10]. To this end, recent developments of Industry 4.0 Key enabling technologies and methodologies have strongly emphasized the role of Simulation, Virtual Reality and Wearable Devices to support operators' training.

As far as the Italian legislation is concerned, the provisions of confined and/or suspected of pollution spaces are contained within the Legislative Decree 81/2008 (a quite consolidated Law on health and safety at work). This law provides rules for working in suspected of pollution spaces (articles 66 and 121) and for working in confined spaces (Annex IV, point 3). While the Italian law does not define a confined and/or pollution suspected space, there are a number of working area that are

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classified as examples of confined or suspected of pollution spaces, as showed in table 1.

Table 1. Confined or suspected of pollution spaces as listed by the Italian law.

Work in confined space with suspect of pollution	Presence of gas in the excavations	Workplace requirements
Cesspool	Well	Tanks
Sewer	Sewer	Ducts
Chimneys	Underground passage	Pipelines
Pit	Chimneys	Containers/storage
Tunnel	Pit	silos
Containers - Silo/storage		
Pipeline		
Boilers and similar		

European and International Agencies currently consider three main characteristics to identify a confined and/or suspected pollution space:

- space with difficulty for entering and leaving;
- space potentially polluted due to an unfavourable natural ventilation;
- space not intended for continuous working activities.

The Machine and Work Equipment Lab at INAIL collected accidents occurred in spaces having the three main characteristics above listed. The data collected and depicted in figure 1 refer to accidents in the period 2001 – 2018 (as appeared from media and online news, therefore to be considered as the most known accidents). These data show that many accidents occur in spaces not directly listed in table 1: 44 accidents occurred in the so called "assimilable spaces", (17 fatal events out of 44 accidents).

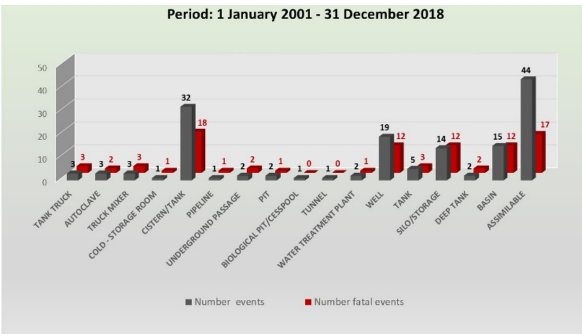

Fig. 1. Data of Accidents in confined and / or suspected pollution space (2001-2018), in Italy

An in-depth analysis of the accidents in assimilable spaces show that, while assimilable spaces have risk conditions comparable to those identified for confined and/or pollution suspected space, these spaces have many different geometrical and environmental conditions and the operators must be specifically trained for working safely in these spaces.

The main goal of this article is to present a physical simulator conceived and developed by the Italian National Institute for Insurance against Accidents at Work (INAIL) and to show how this simulator could profitably be coupled with a Virtual Reality and Immersive Environment to support training in both confined and/or pollution suspected space (as they are defined by the legislation) and in assimilable spaces.

2. Live Simulation versus Virtual Reality Training

Traditionally Education & Training are usually performed in classrooms or, in case of training for emergency procedures, by using physical simulation. In this specific case, it requires the use real resources (people and equipment) as well as detailed information to develop each part of the training exercise. Furthermore, even when people and equipment are available, the number of exercises is usually limited by the time needed to carry-out a real exercise and by the cost.

Using physical exercises for training introduce some critical issues due to:

- long preparation;
- repetitive exercise;
- few exercises;
- small scenarios;
- no dynamic evolution;
- limited collaboration opportunities.

However, physical exercises (intended as live simulation) provide the trainees with the opportunity to experience real-world critical situations. Examples of successful physical simulation and exercises for operators' training include emergency management for disasters in industrial plants, complex operations in industrial plants and facilities, complex operations in critical infrastructures, military exercises as well as operations in confined spaces.

Oppositely, simulated exercise can reproduce multiple emergency scenarios and address correctly the needs of the real world operators. To this end, the simulation architecture should be able to integrate different procedures and mathematical models to let the operators do what they usually do in the real world systems.

3. The virtual environment for training and the physical simulator

In order to take advantages of both physical exercise and simulated exercise for operators' training, the authors believe that the operators' training done by using virtual environments can be further extended by using a physical simulator. Therefore, the next two sections present the virtual environment for training and the physical simulator respectively.

As far as the virtual environment for training is concerned, a specific training scenario – that can be considered as an assimilable space – is considered (a space within a nuclear plant characterized by specific geometrical and environmental conditions). As far as the physical simulator is concerned, the main characteristics and features are presented.

3.1. The virtual reality environment for training in confined spaces

The confined space training environment described in this article has been developed by University of Calabria. The environment is based on a 3D Virtual, Immersive and Interactive Simulation that provide the trainees with the possibility to experience a realistic simulation by using wearable technologies (specifically HTC VIVE headset). Procedures implemented within the virtual environment have been defined according to the Italian legislation and best practices provided by INAIL [11]. The training scenario recreated in the Virtual Environment is set within a confined space that is part of a Nuclear Plant. Within the virtual confined space, the operator must execute maintenance operations that could expose him/her as well as other team members to serious risks if the required procedures are not executed correctly.

The maintenance operations must be executed in a confined space where the percentage of oxygen is limited. If the operator fails in conducting properly all the procedures needed to operate in the confined space, he/she will start to loose consciousness. This is simulated by reducing the operator vision within the Virtual Environment and, after some time he/she will lose consciousness and the simulation will be interrupted.

The interruption of the simulation means that the operator is unconscious and that he/she was not able to follow the required procedures to operate safely in the confined space. After the interruption, the simulation can start again if the trainee will accept to "play" the role of the team member that is going to rescue the unconscious operator. The operator providing help must follow the rescue procedures, otherwise he/she will not able to provide relief to the first operator. Therefore, the training Environment has been conceived to train both the primary operator (the one operating in the confined space) and the operator that is required to intervene (and to provide rescue). Below a more detailed description of the Training Environment is provided.

At the beginning of the simulation, the trainee, that is playing the role of the operator performing the maintenance operation within the confined space, must fence the area of interest to indicate clearly the presence of operations in that area (see figure 2). The operator must also add a tag next to the access of the area to indicate workers operating in confined spaces (see figure 3).

Fig. 2. Virtual Environment: area to be fenced

Fig. 3. Virtual Environment: confined space frame

After that, the trainee must select the Personal Protective Equipment (PPEs) necessary to perform his/her tasks safely within that confined space. Among others, the PPEs include gas mask, helmet, oxygen detector, oxygen tank, gloves, the safety belt for tripod anchor point. Moreover, the operators must collect the equipment and tools necessary to carry out the maintenance operation.

Once ready, the trainee can "enter" into the virtual confined space that is located underground, under the floor depicted in figure 2. To access the confined space, the trainee must properly use an elevator. The figure 4 shows the confined space and the place where the maintenance operations are needed (green arrow in figure 4). The figure 5 shows a trainee wearing the HTC VIVE set while performing training operations at CAL-TEK Company (CAL-TEK is a spin-off company of the University of Calabria that has carried out the development of the Training Environment).

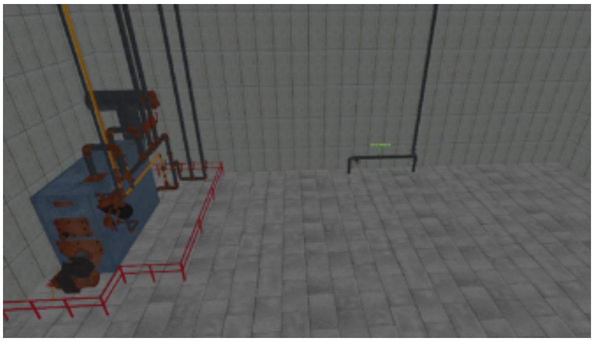

Fig. 4. The confined space within the virtual environment

Fig. 5. Training by using Virtual Reality Headset

If the trainee does not execute properly all the procedures (e.g. he forgets to take the gas mask, he forgets to take the oxygen task, he spends too much time in the confined space, etc.), he will (virtually) loose consciousness. After that, the simulation will start again from the beginning (in this case, the operator will play the role of team member providing relief).

By using two joysticks and being totally immersed within the Virtual Environment (even in terms of sounds), the trainee can practice as he usually do in the real environment. Obviously, the exercise is characterized by a number of stochastic variables that makes the simulation more complex, such as: percentage of oxygen in the confined space, length of the maintenance operations, time to react to the reduction of the vision, failure of the equipment (e.g. failure of the elevator, failure of the oxygen mask/tank, etc.). At the end of the simulation, there is a summary report including the errors made by the trainee within the Virtual Environment (for debriefing purposes and learning outcomes).

3.2. The Physical simulator

In order to extend the training capabilities provided by the virtual environments, INAIL has conceived and developed a physical simulator (see Fig. 6) to integrate both traditional and innovative training for worker in confined and /or pollution suspected spaces. The physical simulator depicted in figure 6 has an Italian patent and the European and international patenting is currently in progress.

Fig. 6. INAIL physical simulator for training in confined and/or pollution suspected spaces

The simulator physically reproduce confined and/or suspected of pollution spaces and some critical situations can characterize working activities. The physical simulator consists in a transportable container equipped with a ladder to access to the top (see Fig. 7). Rails protect the top and a vertical manhole allows the descent of the trainees. It is possible to modify the internal conditions using movable parts, light effects, noise sources. A thermo-camera system performs a continuous observation of operations from the control room (see Fig. 8).

The physical simulator aims at enhancing safety procedures and extending training capabilities. Indeed, a physical training drive the operator in performing specific tasks safely such as restricted walk with obstacles while the operator is equipped and dressed in a like-work way (wearing PPEs and tools). Moreover, it is possible to simulate emergency procedures inside a real restricted area, rescuing an operator through a vertical or horizontal manhole. The operator is also able to save the injured operator using the right equipment such as rescue cranes for the vertical escaping or gurneys for horizontal transportation.

The physical simulator can seamlessly extend the virtual one with the unpredictable human factor. Workers involved in complex operations such as those executed in confined spaces are exposed to specific risks and conditions. These factors deeply affect the human behavior and, therefore, the procedures being performed as showed in different works in literature [12].

Fig. 7. Ladder to access the top of the container hosting the physical simulator.

Fig. 8. Control room of the physical simulator.

4. Remarks and Conclusions

The main idea proposed in this article is to jointly use physical exercises within Physical Simulator and Virtual Reality (Modeling & Simulation jointly used with Virtual Environment, Virtual Reality and Wearable Technologies) to carry out training for workers in confined and/or pollution suspected spaces. By following this approach, the operators may have the possibility to:

- understand the ongoing situation (have a full knowledge of risks and how they can evolve over the time);

- experience both real scenarios as well as a number of simulated (and stochastically generated) scenarios;
- understand the importance of interactions with other people and the correct way to interoperate with them to solve criticalities easily and effective.

As far as the simulation side is concerned, the simulation solutions should be able to reproduce multiple emergency scenarios and address correctly the needs of the real world operators. For this purpose, the simulation architecture should be able to integrate different procedures and models (procedures to let the operators do what they usually do in the real world system while models allows simulating realistically the operations being considered).

Future research activities will be carried out to define training scenarios and sessions to improve the skills and performances of trainees working in confined and/or pollution suspected spaces. The main idea is to enlarge the number of possible training scenarios to include, as much as possible, examples of assimilable spaces (this will allow recreating scenarios that often happen in real life, both in terms of hazards and consequent risks for the operator). The training scenarios will be also enlarged in terms of types of workplace, trying to include industrial sites such as petrochemical, wine, nuclear, construction, ceramics, agro food, livestock and others.

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