Title:
A Customizable VR system for Operator Training

Authors:
Franca Giannini, franca.giannini@ge.imati.cnr.it, IMATI, Consiglio Nazionale delle Ricerche
Katia Lupinetti, katia.lupinetti@ge.imati.cnr.it, IMATI, Consiglio Nazionale delle Ricerche
Marina Monti, marina.monti@ge.imati.cnr.it, IMATI, Consiglio Nazionale delle Ricerche
Yuanju Zhu, yuanju.zhu@ge.imati.cnr.it, IMATI, Consiglio Nazionale delle Ricerche
Luca Mantelli, luca.mantelli@edu.unige.it, TPG, Università degli Studi di Genova
Sara Anastasi, s.anastasi@inail.it, DIT, Istituto Nazionale Assicurazione contro gli Infortuni sul Lavoro
Giuseppe Augugliaro, g.augugliaro@inail.it, DIT, Istituto Nazionale Assicurazione contro gli Infortuni sul Lavoro
Luigi Monica, l.monica@inail.it, DIT, Istituto Nazionale Assicurazione contro gli Infortuni sul Lavoro

Keywords:
Virtual reality, smart objects, simulation, training

DOI: 10.14733/cadconfP.2022.220-224

Introduction:
Regardless of the increasing attention to safety aspects and the development and integration of automation and remote-control processes, the number of worker accidents is still high. Work environments involving hazardous material or high-risk exposure maintain an intrinsic danger that can be reduced but not canceled. The majority of the accidents occurring in the workplace are caused by human errors mainly due to inadequate maintenance of the working tools, lack of knowledge and underestimation of the risks related to the activities performed. Then it is crucial that workers gain the necessary skills to minimize the probability of error and malfunction of the equipment used. To this aim, current regulations require participation in specific training courses aimed at creating awareness and knowledge of the procedures to follow. In addition, for instance, in Italy, they compel a qualification degree for the management and maintenance of dangerous equipment. In the case of steam and superheated boilers, an on-job learning period is also required. This learning-by-doing activity is inherently dangerous and is generally limited to carry out activities in regular situations. Therefore, even if it is adequate to learn the procedures for the daily operations and periodic maintenance of the equipment; it is limited in learning how to deal with critical situations, emergencies, malfunctions, or with the consequences of incorrect operations, being generally (and hopefully) limited to theory and thus lacking effective feedback in practice. Therefore, exploiting the possibilities provided by the most recent technological developments allows, on one hand, the simulation of physical, chemical, and mechanical phenomena and, on the other hand, the creation of immersive virtual reality (VR) systems in this way it is possible to experiment a great variety of situations in safe conditions in realistic environments [4].

The use of VR immersive systems for the training of operators in various industrial contexts is becoming more and more common [1-4]. For several decades in some contexts (e.g., aeronautics) simulation has been considered as the indispensable "alternative" way to learn and to experiment "concretely" activities, in particular, to deal with unusual and potentially dangerous emergencies. Simulations offer the advantage of creating a "protected environment" in which it is possible to actively learn and teach by exploiting errors as resources. In a virtual environment it is possible to simulate situations at different degrees of complexity, thus favoring the realization of a structured learning path, in which it is easy to access demonstrative, technical and regulatory material while carrying out operations. The ability to link the actions and changes of the parameters of the working tools to mathematical algorithms capable of simulating the actual activity of the process drastically expands the set of verifiable situations and the quality of learning.

Despite these advantages, the creation of such training system is still challenging: developing a VR-based Training System requires a truly multidisciplinary approach [4] demanding expertise in various fields, such as dynamic modelling of process, programming tools, and subject domain experts. Thus, a fundamental requirement of such a training platform is the ease of configuration to adapt the virtual environment to new learning scenarios, leaving the expert the possibility to specify new training paths using familiar tools and minimizing the need to reprogram the system. This is particularly crucial when different equipment models should be considered. This is the case, for instance, of the training of steam boiler operators, who are required to be trained on equipment of different capacity to attain the related qualification degree in Italy.

In this case, to fully exploit the benefit of a virtual training system to support the various qualification paths, the system should be easily configurable to represent the different types of steam generators and be able to reproduce the greatest number of possible situations that need to be addressed by the trainees. This requires the specification of the possible scenarios, which include the different steam boilers and the initial conditions under which the trainee has to operate along with the correct sequence of operations he/she should perform to successfully complete a specific task.

In this paper, a customizable immersive system for the training of two different categories of users of steam generators (i.e., operators and verifiers) is presented; the system is based on a model of the equipment composed of reusable elements that encapsulate all the information necessary for user interactions and functional simulations. The functional information, expressed as the status of the elements that characterize the different scenarios are expressed using simple spreadsheet files.

<u>The training systems for steam generator operators and verifiers</u>

Within the PISTOP project [5] funded by INAIL (Italian Workers‘ Compensation Authority), a simulator in immersive VR has being developed to support the on-site learning-by-doing training for the operators and verifiers of steam boilers. To guarantee a realistic experience, the simulator is developed by using a kind of virtual twin of real generators on which the trainee can experience the tasks to learn. The virtual twin includes 3D models of the boiler layout and of the components with which the trainee must be able to interact, whose behavior in response to the trainee action or to the generator conduct mimics the behavior of the real counterpart. These components are hereafter indicated as actuators (e.g., valves, switches), control elements (e.g., manometers, alarm lights) and safety elements (e.g., safety valve). The generator behavior is simulated thanks to a dynamic model implemented in Matlab-Simulink, developed and calibrated using real data from the physical steam boiler. The VR simulator is developed using Unity game engine. The simulators communicate each other by exchanging the values of the statutes of the actuators, control and safety elements.

The user can interact with the equipment using gestures as he/she would act in reality. Supporting documentation, explanations on equipment components and suggestions on the operations sequence for the specific task are activated in alternative with voice and gaze commands or menu selection in VR.

Since, the accreditation for conducting steam generators varies according to the equipment capacity, requiring an on-job training on equipment of that capacity, it is of utmost importance that the VR training simulator is flexible enough to be easily adapted to different equipment and scenarios and requires at most the involvement of experts of the scenario itself, i.e., the equipment expert. Here, the term scenario refers to the task the trainee has to perform, the status of the equipment before and after the conclusion of the task, the correct sequence of operations to complete the task. Examples of tasks are the shutdown and the startup in different conditions, i.e., first time, after fault problems, after a regular shutdown. When performing these tasks on a steam generator, each main operation always causes the status change of one actuator. Therefore, both the initial and the final status can be expressed in terms of the actuators’ status, whose possible values belong to a limited set. Similarly, it can be noted, there is a limited number of possible types of actuators, control and safety components with a predefined and predictable behavior. This makes it possible to easily adapt the system when changing the equipment on which the operator has to be trained. Based on these assumptions, the core elements to guarantee the desired flexibility are an Object-Oriented organization of data representation of the actuators, control and safety components, as described in the next section, and the use of files for the specification of the equipment elements, status and operations, as shown in Figure 1. The status values of these components are then exchanged between the VR and the functional simulators to drive the dynamic model reproducing the operation of the considered steam boiler.

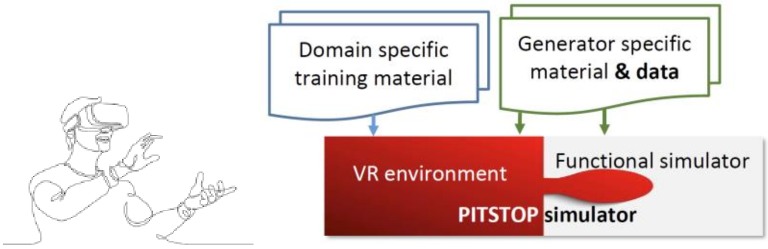

Fig. 1: Organization and configurability of the PISTOP training system.

<u>Modelling key equipment elements for reuse</u>

In the proposed approach, the key operative elements of the equipment can be active and passive. Passive components, i.e., actuators, are those on which the operator can act to change the behavior of the system, indicated as actuators, or to check their working conditions. Differently, the status of the active elements, such as control elements, is automatically changed by the system according to its working conditions, Safety element can be both active and passive. Based on the analyzed steam boilers, the considered control element classes are: warning-light, pressure_gauge, level_indicator, liquid_cristal_display. The considered actuator classes are: button, valve, switch, switch.

The operatives are all characterized by *training data, status*, *behavioral data* and *shape*. *Training data* refer to the material the trainer can associate to each element to communicate to the trainee information useful for the understanding of the element function and related regulations. Status indicates the conditions in which the element can be set, e.g., valve opened or closed. *Behavioral data* refer to how the object is reacting to the user interaction, for passive elements, or is changing according to the dynamic model results in the case of active objects. Thus, in the case of active control elements, *behavioral data* include the status change and the possible color modification and audio effect. Instead for passive elements, *behavioral data* comprise also the type of applicable user gesture and the consequent position transformation in the space. Finally, *shape* refers to the 3D model of the element in the 3D space.

The Object-Oriented methodology has been adopted since it allows the easy exploitation of already defined characteristics through the creation of hierarchy of elements (hierarchy of classes) inheriting some core properties and functions. Therefore, the characteristics shared by all the elements of a specific class have been identified.

To facilitate the reuse, a library of predefined user gestures, sounds and highlight methods are available to be easily associated with the operation element. Based on the analysis of the PITSTOP project's case study, the considered gestures are: finger_push, hand_push, grasp_&_translate, grasp_&_hand_rotation, grasp_&_arm_rotation. The gestures finger_push and hand_push apply to push operation buttons while grasp_&_translate to any movable element. The last two gestures differ in terms of expected movement after the hand has grasped the operation element; in the first case only the hand is rotated, keeping blocked the wrist position; in the second case, the arm is moved while keeping the operation element grasped (see Fig. 2). In the developed system, the grasping action is detected when the user's hand intersects the operation element game object. The considered sound effects currently are: water_flow, steam_flow, working_engine.

(a)

(b)

Fig. 2: Examples of valve (a) and switch (b) actuators with the related operative gestures: grasp_&_arm_rotation (a) and grasp_&_hand_rotation (b).

For each class, a script for the Unity editor is created to support the developer to specify the properties for the instances. According to the considered approach, to change the equipment and define a new 3D model, the expert simply needs to associate the game objects corresponding to operation elements with their classes and to set the relative values and properties.

Scenario setting and control

The possibility of specifying setting information in configuration files allows the domain expert to easily modify some configurations and/or expand the training scenarios avoiding software modifications when simple changes occur.

Analyzing the characteristics of the initial configuration of equipment a trainee has to face, as well as the expected final status of the plant once the trainee has correctly completed the training tasks, it turns out that the single assignment can be easily described in terms of the statuses of the various key operative elements. Similarly, each action that the trainee has to perform to complete the assigned task results in a change of the status value of one actuator. Therefore, the sequence of actions can be expressed in terms of the status values of the actuators elements that have to be operated in the expected order.

Based on these considerations and as the number of key operative elements of steam generators is limited, they can be indicated in a text file and their name can be used to instantiate the corresponding classes in the system. Therefore, it is possible to associate the corresponding 3D objects in the Virtual space as indicated in the previous section and they can be used in the corresponding dynamic model. Moreover, also the list of initial and final configurations of the actuators can be specified in a file where the expected status values for each meaningful operation element is indicated.

The file format should be easy to understand by the domain expert, therefore the .xls file format has been chosen, since it naturally organizes content in matrix-like form, with rows and columns. In this way, expected sequences can be easily written using a (n+2) x (n+c+s+1) matrix, where n is the number of actuators, c the number of control elements and s the number of safety elements. In the matrix, for each column the first row indicates the operated actuator, the second row specifies the sequence order in which the actuator can be operated, the other rows indicate the expected status for the corresponding operative element indicated in the first column.

Therefore, the verification that the trainee is acting correctly on a given actuator can be performed by checking if the operation has some prerequisites, i.e., verifying if the not NULL values in the column correspond to the values of the status of the related operative element.

Conclusions and future work

With the aim of providing an easily adaptable system for the immersive training of steam generator operators, that allows domain experts to define new scenarios without any or little support of the system programmers, this paper describes a two-fold proposal.

It is based on an object-oriented approach for specifying the behavior and interaction modes in VR of the elements that allow bidirectional communication between trainee and equipment; that is to naturally maneuver the equipment and to communicate to the trainee information on the equipment operating conditions. This allows an easier re-use of the programmed VR simulation methods when dealing with new equipment. Moreover, the proposed approach includes the use of external files, directly specified by the domain expert, to express initial and final status of the operation elements involved in the assigned tasks, and the sequences of operations expected for their accomplishment. The main strengths and limitations of this approach regard the specification of operations in terms of change of status of the elements used to control the equipment. On the one hand, the expert is not obliged to provide all the acceptable alternative sequences when an operation can be done in different moments with the only requirement to be performed before a specific one. On the other hand, the system does not support the specification and automatic verification of actions not directly related to the actuators elements. Even if the current development is specific for steam boiler, the approach is applicable to any type of equipment, for which conducting operations can be expressed in terms of conditions on the statuses of their key operative elements. Future work will focus on demonstrating the extendibility with another steam boiler and on the user testing to verify the usability.

Acknowledgements

The presented work has been supported by the project “PITSTOP: Piattaforma Immersiva per il Training STrutturato dell’OPeratore”, funded by INAIL, Bando BRIC 2019. The authors thanks prof. Alberto Traverso and Marco Ferrando for their support in the dynamic model development and the specification of the activities for the operator training.

References

[1] Adami, P.; Rodrigues, P. B.; Woods, P. J.; Becerik-Gerber, B.; Soibelman, L.; Copur-Gencturk, Y.; Lucas, G.: Effectiveness of VR-based training on improving construction workers’ knowledge, skills, and safety behavior in robotic teleoperation, Advanced Engineering Informatics, 50, 2021. https://doi.org/10.1016/j.aei.2021.101431.

[2] Kumar, V. V.; Carberry, D.; Beenfeldt, C.; Andersson, M. P.; Mansouri,S. S.; Gallucci, F.: Virtual reality in chemical and biochemical engineering education and training, Education for Chemical Engineers, 36, 2021, 143-153, https://doi.org/10.1016/j.ece.2021.05.002

[3] Mujika, A., Oyarzun, D., Iparragirre, I., Dominguez, J., Arambarri, J., MACHS: An authoring tool to create serious games for machine-tool operator training, 9th International Conference on Emerging eLearning Technologies and Applications (ICETA), 2011, 147-152, https://doi.org/10.1109/ICETA.2011.6112604

[4] Patle, D.S., Manca, D., Nazir, S. et al.: Operator training simulators in virtual reality environment for process operators: a review. Virtual Reality 23(2), 2019, 93–311 https://doi.org/10.1007/s10055-018-0354-3

[5] PITSTOP, http://pitstop.ge.imati.cnr.it/, last accessed 2022/1/12