A Design Proposal: Virtual Reality Environment for Safety Training in Electrical Substations

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Abstract. Virtual reality technology has developed at an exponential rate in the last decades, increasing in popularity due to its multiple benefits in learning and job training applications. One of these benefits is the ability to offer hands-on learning in virtual environments, which in real life are highly dangerous for inexperienced people, so it would be impossible to provide this type of learning through traditional teaching methods. In electrical engineering, it is common to encounter these situations, as is the case with electrical substations. There is a need for a trainer that allows trainees to acquire knowledge about these infrastructures with a closer approach. Being substation safety is one of the main factors in the training process in the electrical field. The trainer must have scenarios that first teach and promote personal safety, so topics such as personal protective equipment are considered. This paper introduces the process of a trainer for electrical substations simulator, specifically on following safety instructions, a development of a virtual practice using 2D and 3D is shown, which aims to instruct the user on personal protective equipment in an immersive environment. The process of the three-dimensional environment is presented, and the flow of the practice is described. The training tool teaches the users about the proper equipment to wear when going to an electrical substation and then shows what the user will find there. Tests were applied to the user to measure usability, satisfaction, and efficiency using the training tool.

Keywords: Virtual reality · Training · Electrical substation

1 Introduction

When it comes to the practical knowledge, traditional teaching methods are often insufficient in many areas, such as medicine [1, 2], construction [3], even chemistry [4] and engineering in general [5]. Although there are certain approaches to practical instruction, the lessons are often limited to observation by means of images or elements that are not in operation, or in their common environment. For subjects such as medicine, anatomical models that emulate the human body [6], or videos explaining procedures, are often used. Likewise, for construction [3], diagrams, pictures, and videos are used. It is very unusual that lessons are given in real situations, since the lack of experience of the

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trainee, and the environments in which these practices should be given would represent a considerable risk for the trainee, the infrastructure, and other personnel around him/her.

In engineering, specifically electrical engineering, the same situations apply. Trainees are taught about components and infrastructures that are not in operation or are isolated components. Such is the case of electrical substations, highly dangerous installations for inexperienced personnel, where each component is energized with high voltages and currents that represent lethal risks. In addition, substations are often located in remote places, which also implies transportation costs in case trainees wanted to be trained there.

Practical training at real substations is an obstacle for schools and students since there are some factors that impede his practical realization. There are situations such as safety of personnel, not being able to make any mistakes in matters of safety, transportation of personnel, the need to be guided by a host visit, technical requirements to train at real situations (schedule and times), and the cost of the equipment to train personnel [7].

Virtual reality allows facing the problem of the risks involved in the training of people with no or minimal training in different areas. In matters of safety, it is also known that there is a high rate of injuries related to the engineering and construction sciences that is the reason why the development of new technologies for implementation and experimentation has been a priority in recent years [8]. A relevant subject is also to provide the users the capability to assess their knowledge [9]. In the last decade alone, multiple proposals and projects have been developed for virtual reality systems for training in different areas. For example, in medicine, [1] describes the development of a non-immersive virtual reality system, using 3D vision, for the exploration of an anatomical model in breast cancer situations. In this work the evaluation of the users suggests an improvement in learning, being able to investigate the human body without the common restrictions, and being anatomically accurate models, in which it is possible to explore internally without the need to make cuts to a real person. In [2] is discussed the development of a virtual reality system for training in endovascular surgery, specifically to avoid collisions that could damage blood vessels when manipulating the catheter, due to the lack of the notion of the force applied in the teleoperated systems. The system warns beginners about possible collisions and assists the user in eliminating them. The evaluation of this system shows a reduction in the frequency of collisions and the distance that represents tissue damage. This means that it allows practical training of novice physicians in such procedures, without the need for trial and error with real patients, which would be highly irresponsible and dangerous. In [6] the procedures known as "T\&S" are described as procedures that require high levels of practice, which evidently cannot be obtained without real patients. Therefore, a virtual reality system is developed to facilitate the training of this procedure without the risk of involving patients who could be negatively affected by a poorly performed procedure. In terms of construction virtual reality is used to generate learning about safety in construction and engineering environments. The potential of this technology with HMD's (Head Mounted Displays) for visualization and planning in architecture and construction projects is also discussed [3, 10–12].

In electrical engineering, there are multiple projects focused on the development of virtual reality systems for training. In [13] a non-immersive virtual reality tool for maintenance of high voltage overhead lines is presented, where the non-immersive is justified because it enables the use of other more common peripherals for the user, reducing costs and training time in its use. More specifically about electrical substations, in [14] a virtual reality substation trainer is presented. In it we see great freedom of interaction and decision making for the user, giving him the ability to make decisions of free actions, even if incorrect, with visible consequences. The freedom of interaction translates into more realistic and meaningful experiences, in terms of learning. More recently in [15] the development of a so-called virtual reality training complex for power systems is shown. This is aimed at training and practice of personnel actions during common and emergency situations. It is proposed that the user will gain experience, eliminating the possibility of electric shock and equipment failure. It precisely states that if a practical approach to training is impossible due to lack of competence and potential danger, virtual reality environments can be used to acquire these competencies in a safe way. To create a trainer, procedures should be modeled in a way user decisions have to value for training. Instead of following a sequence of static steps, the model of any software needs to have options depending on the situation [16]. Many specific topics are addressed in the papers presented, such as maneuvering, exploration, etc.; however, few proposals focus on the personal safety of the user, who will eventually find himself personally in electrical substations, facing various lethal hazards.

The objective, given the above, is to develop a virtual reality trainer for electrical substations, specifically focused on electrical substation safety. The trainer will consist of multiple practices that will instruct the user in the safety measures to be followed when working in the facilities.

2 Materials and Methods

2.1 Methods

The method is focused on the development of an environment that the user could relate to a real workplace, based on different models already implemented [17, 18]. Prior to any development, the knowledge of experts, electrical engineers with extensive experience in the field, was sought to obtain a first approach to the environment to be developed as we can see in [19, 20] with related works. As a result of this approach, information was gathered on the environment and the development of common procedures in electrical substations, as well as safety issues corresponding to the environment. Subsequently, the main concept of the trainer, personal safety, was established.

The construction of different virtual environments began, making use of three-dimensional models for each object or room present in the trainer inspired also on models already implemented [21, 22]. In these virtual environments, the user can interact and perform a series of specific activities, which provide practical knowledge on safe practice.

After the development of the trainer, the proposal scenario has been completed, usability and heuristic tests were applied. A group of users did the virtual trainer exercises and then answered a survey used as a test. Tests were applied to 12 not experienced users and to 10 professional users. Both tests had questions designed according to specific aspects of the interaction between the user and the training tool. Each question used the

Likert scale, so the user selected one of five possible answers. Usability tests focus on how simple was for a user to understand what to do and do it. Heuristic tests evaluated how the user felt while using the task, in terms of satisfaction, motivation and how effective they could complete the objectives of the task. After development, the training tool was tested.

2.2 Materials

The scenarios are built in Unity 3D software. The models used for each scenario are three-dimensional models with textures and materials that provide a more realistic visualization. The 3DS Max software was used. Events and interactions are generated through C# programming, and through Unity 3D tools, codes are assigned to models to allow interactions with them. Two platforms were designed, one using a VR Oculus Quest SDK, to provide greater immersion of the user in the environment. The second platform was a desktop version that will be maintained for a wider scope. These tools were used in different projects using Virtual Reality and Virtual Environments [23, 24].

2.3 Definition of Practices

One of the most important parts when performing maneuvers in an electrical substation is the proper use of personal protective equipment, and it complies with certain specific characteristics to avoid any accident. The first practice consists of the trainee becoming familiar with and correctly identifying the personal protective equipment to be used, selecting the correct equipment from among various models of personal protective equipment.

For a second practice, in a virtual electrical substation influenced [25], the user will learn about safe distances to maintain from certain elements of a substation to minimize the risk of electrical shock [5]. The practice consists of a guided walk through the electrical substation, in which the user is instructed to go to certain areas but alerted when an area is considered unsafe [26]. The consequences of not respecting these distances, such as an electric shock, are also included.

3 Results

3.1 Equipment Selection

The exercise for the first practice consists of indicating to the engineers which equipment they need to go to an electrical substation. The flow of interactions for the first practice has also been designed, from the start and user prompts to the final evaluation of the user's performance. Each part considered can be found listed below. In the beginning, the trainee will appear in front of a screen, on which he/she will be able to read the objective of the practice. This screen will change, giving context and indications on how to proceed.

The user will be instructed, through the screen, to explore the warehouse in search of personal protective equipment for an electrical substation, which should consist of a helmet, goggles, gloves, and boots. The user will find on the shelf distinct types of equipment for each item, i.e., different helmets, glasses, gloves, and boots. The user must select from each item the correct one to be used in a substation. Once the user has finished selecting the equipment, he/she considers appropriate, he/she must trigger the evaluation through a control (Model that will serve as a trigger for the evaluation).

If all selections have been correct, positive feedback will be given to the trainee, otherwise negative feedback will be shown. The latter will consist of a message explaining that, due to a bad choice of equipment, a serious accident happened while in the electrical substation, so that a strong impression is generated in the user about what not using the right safety equipment could imply.

The scene simulates a warehouse. The user can navigate the room and choose the equipment he needs to go to a substation. The first exercise teaches the user what to do before he is in an electrical substation.

In this warehouse, you can find furniture, such as tables, shelves, racks, doors, lockers. Figure 1 shows a section of the virtual warehouse with tables and lockers. There is also a screen, on which objectives and instructions are indicated.

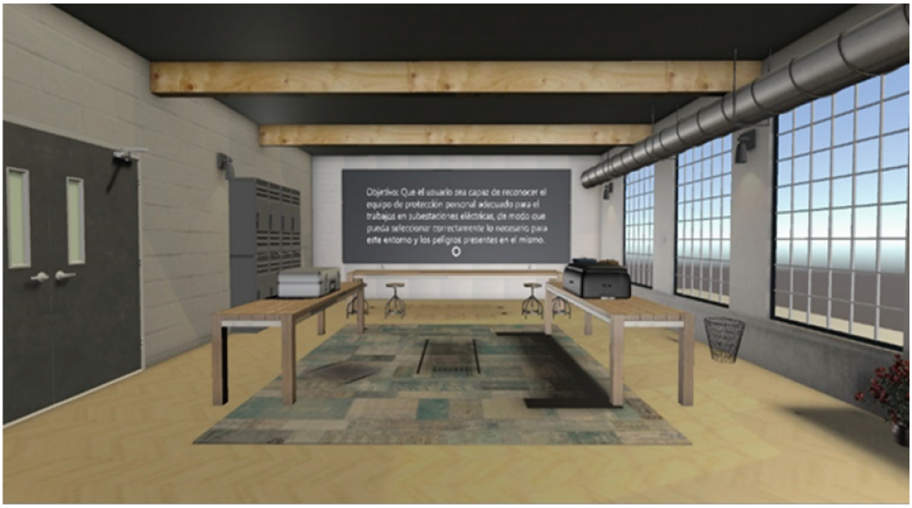

Fig. 1. Screen with objective of the first practice.

In Fig. 2 a view of the room is shown from another point. You can see the tables, some decorative elements, and in the background, you can see shelves containing some of the models of personal protective equipment. These elements are added to simulate a real room.

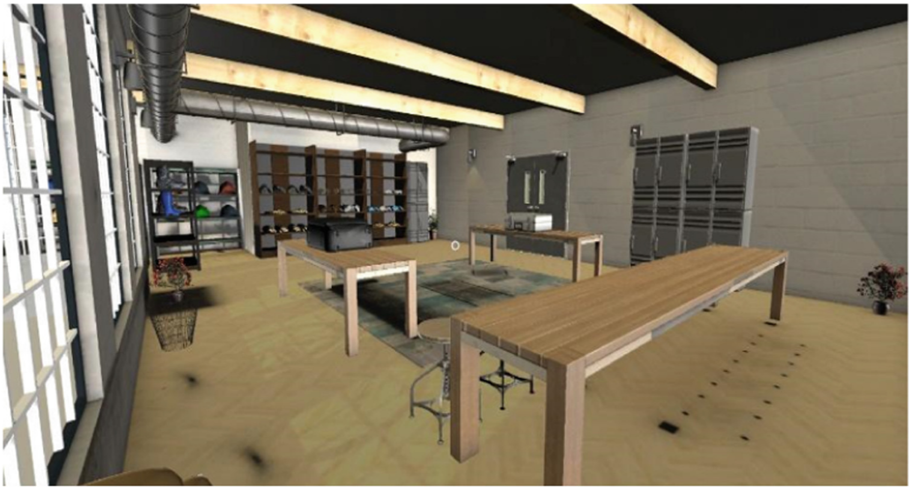

Fig. 2. View of the warehouse of the first practice.

The warehouse has different models of personal protective equipment in 4 categories: helmets, gloves, goggles, and boots. These are located on shelves and racks. As shown in Fig. 3 there are multiple models of gloves of different materials and textures, as well as multiple models of glasses. For the user to have information about the models, when he focuses on a model, a sign with information and a description of the object appears (Fig. 4).

Fig. 3. Different models of gloves and lenses.

Fig. 4. Information signs of the model displayed in front of the user. Spanish version.

As well as gloves and glasses, there are multiple models of safety helmets and boots. The different helmets represent different class helmets, in accordance with NOM-115-STPS-2009. Similarly, each model for the boots represents different degrees of protection or use. Information regarding these elements is given to the user through signage, as shown in Fig. 5 and Fig. 6.

Fig. 5. Information signage on class E helmet. Spanish version.

Fig. 6. Information signage of industrial cap boots. Spanish version.

3.2 Electrical Substation Tour

After finishing the first practice, the user could continue at the second practice, which is a tour in a small transformer substation (Fig. 7). In this exercise, the user walls across the substation get to know the components of an electrical substation.

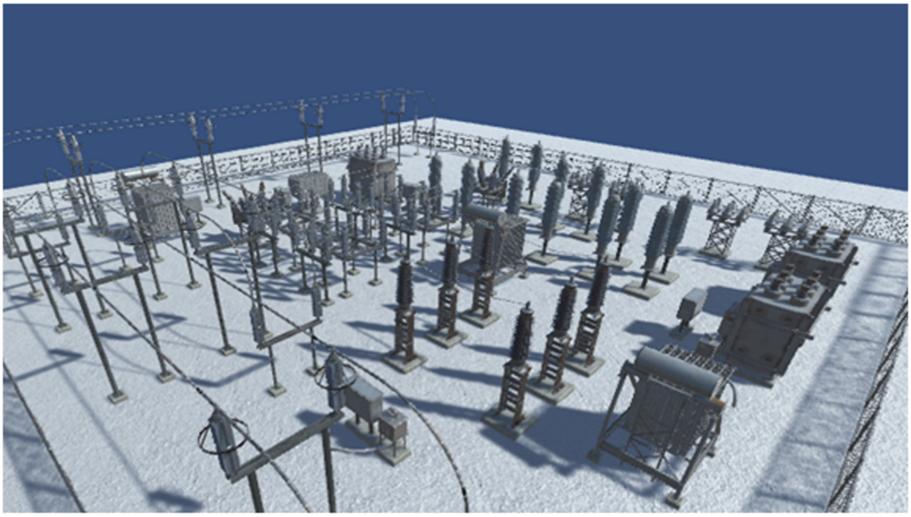

Fig. 7. Multiple models for substations.

Although each substation is different, there are a series of common components. In a substation, the user can find elements as electrical towers, voltage, and current transformers, and switches, all modeled and included in the virtual environments. These elements are shown in Fig. 8. Entries and exits are also included in the scene (Fig. 9).

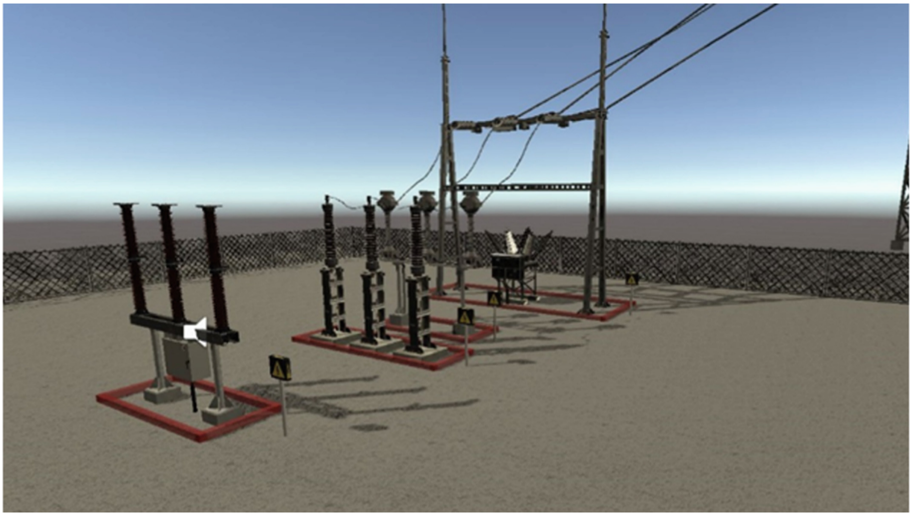

Fig. 8. Switchgear models, current and voltage transformers, and electrical towers.

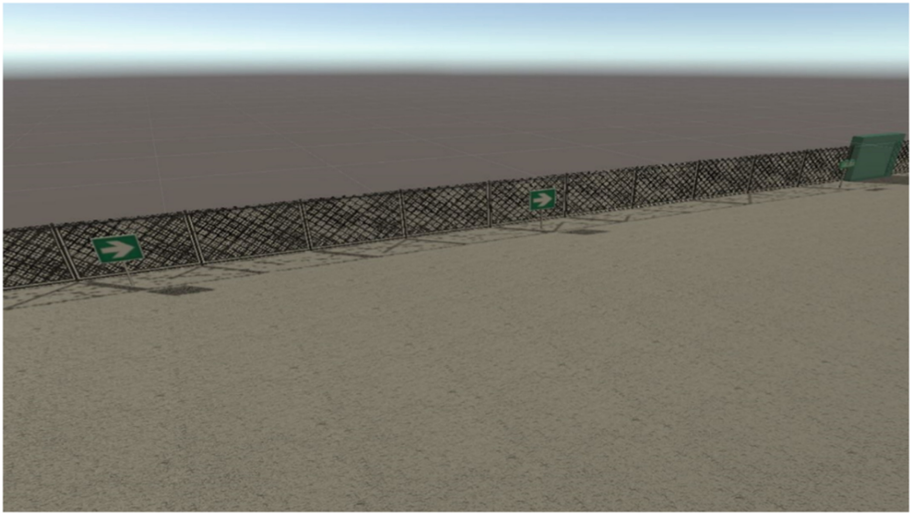

Fig. 9. Portal to leave simulator.

3.3 Evaluation

This step represents the development of the trainer proposal, it has been determined to apply usability tests to electrical engineers with previous experience in interacting with electrical substations. In these tests, the users will be trying the interface (Fig. 10), the different environments, the interactions, and the practices in general. Once the test is finished, they will be asked to fill out a survey, based on which statistical analysis will be made. Comments will also be received regarding approaches to be considered in the simulator. The final objective of this analysis will be to identify areas of opportunity to improve and to have feedback to subsequently provide the trainer with an industrial approach.

Fig. 10. Users testing the immersive environment.

To know the acceptance and experience that the simulator could give to the trainee, three tests using the Likert scale were conducted: usability test, composed of guidance quality and interaction experience, and a heuristic test that evaluated satisfaction, motivation, efficiency, and effectiveness.

For most users, interactions and guidance were acceptable or better. As shown in Fig. 11, no users evaluated interactions as poor or worse, and more than 60% of users answered the interactions were good. In comments the indicated the interface was easy to use. However, guidance can be improved. Around 30% users evaluated the guidance was not complete and require additional indications in how to do the exercises.

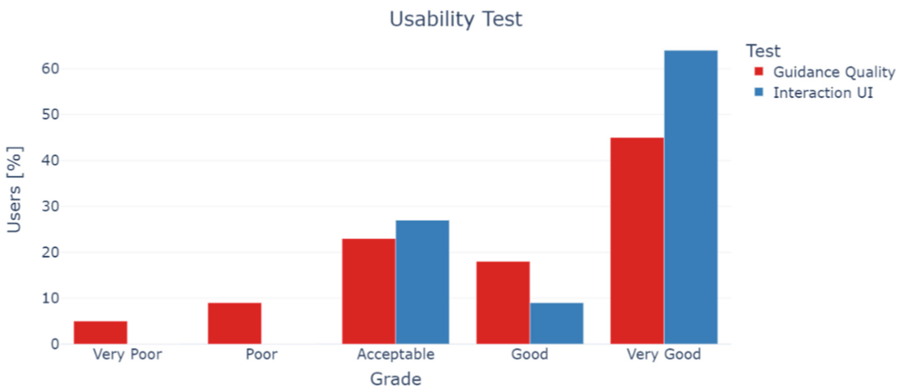

Fig. 11. Usability test results.

The virtual training environment generated user engagement. The heuristic test shows that more than 65% users graded motivation and satisfaction as very good (Fig. 12). Some users added to comments that the use of the virtual training environment was entertained.

Fig. 12. Satisfaction and motivation results.

In the case efficiency questions, all users indicated that the game was good or better (Fig. 13). This indicated the users have no problem doing what the activity required. No bugs were reported in the comments.

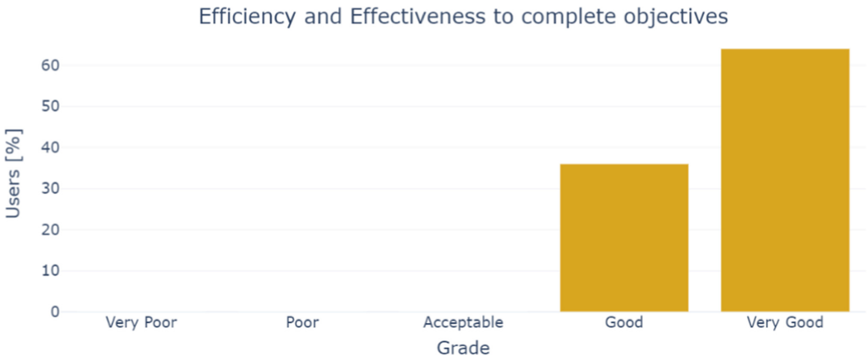

Fig. 13. Efficiency and effectiveness results.

4 Discussion

The guidance could be improved. After efficiency and usability were evaluated, the virtual reality tool was easy to use and attractive for the users. Most users enjoyed the way they interact with virtual elements. However, a group of users felt lost in the second exercise. In the first one, there is a text with instructions while moving in the warehouse. On the other hand, the second exercise only indicated what to do at the start of the actions. For training, indications should be modified in the second exercise.

For a virtual reality simulation to keep improving, developers need to keep track of how technology changes. New technology generates new methodologies. In fields like manufacturing, there are constant proposals in how to improve the design of elements [27]. Electrical substation maintenance can also be affected by new proposals. Although the results of the current version of the virtual reality environment were considered effective by the users and are based on current methods, once there are new elements in the methods, the current version is no longer useful for learning. Changes in how to do a specific task should be also modified in a virtual environment to keep being useful for learners.

5 Conclusions

Virtual environments currently represent a solution to support the acquisition of practical experience, without the need to worry about risks to the health or life of the trainee, or to produce failures in the installations, caused by poor operation due to lack of experience. It has been decided to follow a safety approach, because, despite the previous existence of other works on electrical substations, few consider the user's safety in the first place. Ensuring the safety of personnel is fundamental, and many of the accidents that occur in these environments are due precisely to lack of training or experience. The exposed VR simulator has allowed the user to learn about safety procedures at an electrical substation, from the validation of personal protective equipment to interaction with the equipment in operation in electrical substations. As a result of a good level of acceptance, represented by the usability results, it is expected to continue the next practice that will be of significant help in generating practical learning. Improving the guidance support and the efficiency, incorporating the next scene will permit to know the level of learning using an evaluation process that will be store the trainees' actions into a database.

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