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A VIRTUAL REALITY SIMULATOR FOR TRAINING ELECTRICIANS TO WORK ON ELECTRIC POWER DISTRIBUTION NETWORK

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ABSTRACT

Immersive virtual reality simulators have been adopted in formal education and corporate trainings as they can represent real world scenarios, conditions and events that have inherent risks and/or that are not easily reproducible on classrooms or laboratories. One of the areas that can use these simulators is the electric power distribution network. Especially in Brazil, electricians take formal trainings to work on the electric power distribution network but usually do not experience the real conditions of the network and the several risks involved with it during these trainings. Consequently, even after taking the whole trainings, the electricians may not be well prepared to work on the emergency services or even on some of the scheduled maintenance services of the network, taking longer than expected to conclude these services. Therefore, this paper presents the development of an immersive virtual reality simulator for training electricians to work on the distribution network, considering the safety procedures, the proper usage of equipment and the collaboration with other electricians. By practicing in the proposed simulator, it is expected to improve the trainings and to expand the knowledge and the skills of the electricians.

KEYWORDS

Corporate Training, Virtual Reality, Simulator, Multi-User

1. INTRODUCTION

Virtual reality (VR) is commonly associated with games and entertainment. However, beyond games and entertainment, VR can be adopted in many different fields: education, automotive industry, healthcare, retail stores, and others (Verdu, 2021) (Bellini, et al., 2016). In education and professional trainings, VR has been adopted especially because it provides free interaction with realistic 3D objects with no risks while it can also promote active practices that, quite often, are not possible in regular classes (Mikropoulos, et al., 1997). According to Mikropoulos et al. (1997) and Pantelidis (1994), the usage of VR in a teaching and learning context is adequate when the users:

- Can't make mistakes in the real environments, because they can harm themselves or other people or even cause damages to the environment;
- Are not allowed to practice in the real environments;
- Are motivated to interact with simulated objects;
- Need to view, manipulate and organize information to acquire a specific knowledge;
- Develop or practice activities that are only possible in a virtual environment;

Additionally, by practicing in VR environments, users can try different approaches to solve problems as many times as they want, with no pressure of a classroom or a formal assessment (Patel, et al., 2006). Therefore, these environments encourage users to lead their own learning (Mikropoulos, et al., 1997).

Some VR environments for educational purposes are stand-alone experiences, designed for a single user. However, many of these environments allow collaboration and cooperation among users. That is the case of the EcoMUVE (Grotzer, et al., 2011), a set of virtual reality environments developed for high school students to learn about ecosystems and complex causal patterns. In addition, medical courses are continually adopting multi-user VR environments, especially to visualize 3D models representing parts of the human body and organs. One of the greatest advantages of this kind of VR environment to view medical models is to allow a collaborative analysis of these models with tools such as voice communication, pointers to highlight specific areas and to rotate and resize the models (Silverstein & Dech, 2005).

In professional trainings, multi-user VR environments have been adopted as well. Passos et al. (2017) developed a VR environment for training security agents in very large events such as the Olympic Games and the World Cup, as it is not easy to simulate emergency or critical situations in the real world environments. In the proposed VR environment, security agents need to collaborate and communicate with each other to identify potential security risks or suspects, guide the public and, eventually, isolate and/or eliminate the risks. According to the authors, the results of the user tests showed that the security agents were able to develop a sense of collaborative actions.

Other example of a multi-user VR environment for professional training is from Le et al. (2015). The proposed VR environment aimed to educate construction professionals about safe work and the correct usage of protective equipment, as not always these professionals are aware of the risks and this is a typical area with high accident rates, increasing costs and delaying the conclusion of the construction. Using realistic scenarios, users need collaborate to inspect risks and share with others their findings in the proposed VR environment, improving their knowledge about safety practices.

One of the potential fields of usage of multi-user VR environments is in the electric power distribution system. During the current trainings, many of the electricians in Brazil have only formal classes (in a classroom) and some practical activities in special training centers that usually represent some parts of the electrical distribution network and contain poles, cables, distribution transformers, switches and other equipment. However, these training centers often do not have all equipment that the electricians can find in the distribution network. Moreover, they do not represent the real environment and conditions that the electricians will face when going to the field: high traffic streets, trees that conflict with the distribution network cables, consumers that may not be satisfied with the service, dogs, bees and other animals that may be a threat, different weather conditions (wind, heavy rain, fog, and others).

Considering the gaps present in the current trainings for electricians to work on the electric power distribution network, this paper presents a multi-user, VR simulator that aims to offer realistic scenarios and situations that cannot be easily reproduced in the training centers. With the proposed simulator, it is expected that the electricians learn the safety procedures and best practices, the correct usage of Personal Protective Equipment (PPE) and Collective Protective Equipment (CPE), in addition to enhance the sense of collaboration among them.

The next sections present some related work, the development of the simulator and the results for far.

2. RELATED WORK

In general, professional trainings for the electric power distribution system in Brazil encompass formal classes and practical activities in the training centers. Most of the formal classes are expositive only and do not promote problem-solving situations or even interaction among the students. On the other hand, in the training centers, the electricians are allowed to view and interact with some of the distribution network equipment and get familiar with the safety procedures and the protective equipment. Nevertheless, the training centers have a restricted amount and variety of the equipment and, often, do not represent the real conditions of the distribution network and the risks that electricians may find on the field, such as animals and bad weather conditions.

Due to the complexity and the risks involved with the electric power distribution system, an effective and efficient training for electricians is a key factor to achieve safety, reliability and quality of the services. Additionally, when these professionals need to work on any maintenance on the distribution network, if they were effectively trained, the chances are high that they will adopt the best practices and the most appropriate PPE and CPE and, consequently, decrease the risk of accidents.

Thus, simulators for training electricians to work on the electric distribution system in Brazil have been proposed since the last two decades as tools to enhance their knowledge and prevent accidents. Some of them focus only on the visualization of the installations and/or equipment whereas others encourage and require that users interact with the equipment and explore the environment to solve problems. Additionally, a few of them adopted VR to promote immersion and give to the users a realistic and immersive experience.

STOP (de Castro Silva, et al., 2011) is an example of a simple simulator for the electrical system. In this simulator, electricians must analyze and interact with single-line diagrams of electrical systems and configure their equipment such as relays, circuit breakers and power transformers. Also, it is possible to simulate faults in the systems. One of the drawbacks of STOP is that, as the electricians only interact with 2D diagrams of the electrical system, they do not have the experience of interacting with all the equipment present in the system – for example, a user may not be aware of how to operate a circuit breaker present in the real life.

An example of more realistic simulator is Virtual Substation (Silva, 2012), which uses 3D models to represent an electrical substation and its equipment. Although it is possible to interact with these 3D models using joysticks and VR goggles, the look and feel of the equipment is not realistic.

A more recent project also to simulate an electrical substation using VR is from Paludo et al. (2017). In this simulator, all equipment were 3D modelled according to a real substation in Brazil. Also, panels, buttons, switches, disconnectors and other equipment are interactable through motion controllers and the electrician must select PPE and CPE according to the tasks he/she will perform. Moreover, the stress level is monitored using biometric data acquired from a smart band and instructors can analyze the performance of the electricians in the proposed simulator through generated reports available on a Web interface (Paludo, et al., 2017).

Although these simulators can enhance the trainings of professionals, it is interesting to notice that none of them focused on the work of electricians on the distribution network, its equipment and components and the common challenges that electricians find in their routine. Additionally, none of them is a multi-user, VR simulator that allow the collaboration among electricians to solve potential problems.

3. MATERIAL AND METHODS

The major objective of this project is to create a multi-user, VR simulator to enhance the knowledge of electricians to work on typical services on the distribution network, allowing them to practice tasks that, very often, are not possible in current trainings. An electric power distribution network usually includes several equipment and structures such as switches, isolators, cables, distribution transformers and poles. In addition, different elements that may conflict with the network or compromise the work of the electricians may be present, for example, a tree whose branches are in contact with the cables or a hive that is on the top the pole. Moreover, as most of the tasks of an electrician performs are on top of a ladder or in a truck with elevator bucket, these tasks may also have a risk of falling. In other words and as previously mentioned, a VR simulator can be a tool to assist trainings.

To gather details about the most relevant services and tasks performed by electricians to include in the proposed simulator, the equipment that electricians used to work, how they communicate with each other and work as a team, unstructured interviews with electricians, safety specialists, instructors and engineers took place at the beginning of the project. In these interviews, it was clear that, given the inherent risks, all initiatives to prevent accidents and to educate electricians about the best practices, the safety procedures and the proper usage of PPE and CPE are fundamental. After the interviews, a focus group was also conducted with the same participants to raise the pros and cons in current trainings. Furthermore, to understand how electricians work together and how the training classes take place, the researchers went to a training center and attended a training class (as observers) with a group of electricians.

After the interviews, focus group and the attendance of the training class, it was decided to have in the simulator exercises related to services and tasks that, usually, have a high rate of accidents, hurting the electricians or causing damages to the distribution network and that were not easily reproducible on the training centers. As a result, the major recommendation from the participants was to start with a tree pruning exercise using a chainsaw and a truck with elevator bucket to reach the higher branches, as this is a common service that frequently causes accidents.

The proposed simulator has been developed using the Scrum framework. And, to provide the basic functionality and VR support, the simulator is developed using Unity 3D (Unity, 2021) and the SteamVR plugin (Valve Corporation, 2021), supporting the following VR sets at the moment: Oculus Quest (Oculus, 2020), HTC Vive (HTC, 2020) and Windows Mixed

Reality/Lenovo Explorer (Lenovo, 2020). Also, to create a realistic 3D scene, a specialized 3D modelling team has been assisting the project, producing the equipment and all other 3D objects based on technical specifications and documentation, photos and videos. Additionally, all the 3D objects related to the environment have been modeled: streets, sidewalks, vehicles, trees, grass, buildings, houses and road signs.

To create a more realistic and immersive experience, gestures similar to the real ones to manipulate the equipment were implemented in the simulator using motion controllers. For example, to start the chainsaw, a user needs to pull the engine's crank and, to cut some branches of a tree, a user must move the chainsaw to hit the branches. There are also other gestures to manipulate the hot stick: to expand or collapse it and to open and close fuse switches attached to the poles from a safe distance.

Another finding from the interviews, focus group and attending the training class was that, most of the time, electricians work in pairs when performing their tasks and have specific roles: one of them is the executor whereas the other is the supervisor, who must assist the executor and assure his/her safety and other people around. For instance, if a task must be performed on the top of the ladder or the elevator bucket, the supervisor must remain on the ground, preventing strangers to get close of the working area. Therefore, the electricians must talk to each other, so that a radio communicator (through voice) was also implemented to coordinate the execution of the tasks in an exercise.

For each task performed by electricians, there are formal procedures that describe a step-by-step of actions and the required PPE and CPE to mitigate or eliminate risks. Then, in the simulator, the exercises were created based on these step-by-step guides. If an incorrect action is performed in an exercise, it is registered in the exercise log so that instructors can review later. The same happens if the required PPE and CPE were not used. To assist the electricians during the tasks, the documents containing the safety procedures as well as some helpful tutorial videos were included into the simulator and are accessible through a virtual tablet.

As some users may have motion sickness when wearing VR goggles, the simulator can be used without the VR goggles. In this case, users can interact with an ordinary monitor, keyboard and mouse or a gamepad.

To evaluate the development of the simulator, some usability tests were conducted, especially to verify the locomotion. The major results can be found in Tanaka et al. (2020). Also, reviews with electricians, instructors and safety specialists have been conducted during the development of the simulator to validate the step-by-step of the exercises, the required PPE and CPE in the exercises and the equipment in the electric power distribution network present in the virtual scenario. Results from this review will be covered in the next section.

4. RESULTS

Currently, there are four different exercises in the simulator. And, as mentioned in the previous section, the goal of the first exercise is to prune a tree whose branches conflict with the low voltage network. In this tree pruning exercise, the electricians need to perform the following actions, according to the step-by-step guides:

1. Identify the tree to be pruned and check if there are potential risks that may prevent the pruning (for example, bees).

2. Wear the appropriate PPE: helmet, safety glasses, face shield, hearing protection, gloves, safety harness and lanyard.
3. Isolate the working area with signaling cones.
4. While the executor goes up with the elevator bucket and use the chainsaw to select the region of the tree to prune, the supervisor remains close to the truck to assist the executor.
5. After finishing the pruning task, collect the signaling cones back to the truck.

Some data about the execution of an exercise are stored in a log, which can be analyzed by instructors afterwards. For example, if the required step-by-step actions to prune a tree are not properly followed, the simulator creates a log registry. The time spent to perform an exercise, the lack of a required PPE or CPE to do a task and the number of tries until the electricians successfully conclude the exercise are other data stored in the exercise log.

To provide a wide range of options in the tree pruning exercise, instructors can select the type of prune that electricians need to do: an “L-type” on the left or right branches, a containment pruning on the top branches, a hole or a “V-type” on the middle of the tree. Then, when accessing the tree branches, the executor must select the proper region and use the chainsaw to prune it. If an incorrect region is selected, a registry is added to the exercise log too.

Figure 1 shows some screenshots of the proposed simulator. (a) The inventory system, which allows the electricians to pick up PPE, CPE and other equipment. (b) The electrician’s avatar wearing safety glasses, protective gloves, helmet and face shield is equipped with the chainsaw, which is required to perform a tree pruning. (c) The first-person view of an electrician pruning a tree. (d) The supervisor’s view (on the ground) of the scene.

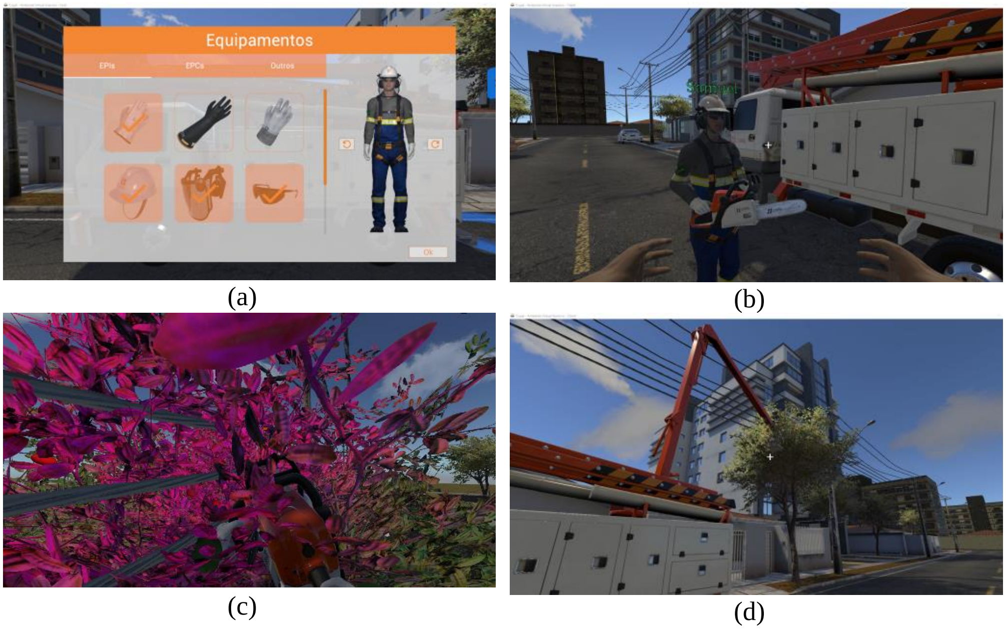

Figure 1. (a) Inventory system; (b) Electrician wearing PPE and equipped with chainsaw; (c) Using the chainsaw to prune some branches of the tree; (d) supervisor’s view

The goals of the other exercises are to open and close fuse switches in the poles and follow a similar procedure, except that, instead of the chainsaw, the electricians use the hot stick to reach the fuse switches on the top of the pole. There is also an exercise to cut a tree near the distribution network using the chainsaw.

In addition to the log of the exercises, the instructors can watch on real time the tasks being performed by the electricians in the simulator through the "watcher" feature. With that feature, instructors can have the same view as the electrician during a simulation or freely navigate through the scenario during the exercise.

To provide a great feeling of immersion, the scenario in the simulator resembles typical streets of medium and large cities in Brazil, with buildings, houses, sidewalks, trees and the electric power distribution network. Furthermore, to bring more conditions that not always can be practiced on the current trainings, the simulator also offers different weather conditions for the exercises: clear weather, foggy, drizzle and storm.

The simulator offers two different locomotion mechanisms in immersive mode (using the VR sets): the continuous and the discrete locomotion. The continuous locomotion is similar to the mechanisms typically adopted in first-person shooter games: by manipulating analog sticks on controllers, a user can move forward and backward, strafe and rotate its camera. To reduce motion sickness, a user can enable the reduction of the field of view (FOV) in the continuous locomotion. In the discrete locomotion, also known as teleport, the user casts a ray in front of him/her and can be teleported to the point where the ray touches a flat surface on the ground. The major reason to support both locomotion mechanisms was that, as noticed in the usability tests, motion sickness was less frequent in discrete locomotion, but it is not a natural or familiar way to move on virtual scenarios, so that many users prefer continuous locomotion. All these findings about the locomotion mechanisms are available on Tanaka et al. (2020).

The feedback from the reviews with electricians, instructors and safety specialists was positive so far. According to them, the proposed simulator has a high level of immersion and a detailed representation of the components of the electric power distribution network (poles, cables, switches, isolators, and others). Additionally, one frequent comment was that, with the simulator, it is possible to verify if the electricians are aware of all required PPE and CPE for the tasks they perform day-to-day and if they are following the safety procedures. Moreover, the simulator allows to practice some services and tasks that can't be frequently done in the current trainings, but that are often required on an electrician's work routine, or some conditions that can't be experienced in the current training, as different weather conditions (especially fog and rain).

In addition to the direct usage of the simulator by electricians to enhance the trainings, instructional designers that create content for the trainings also noticed that, with the "watcher" feature, they can take screenshots of the equipment on the electric power distribution network present in the virtual scenario to enhance other training materials, such as presentations and handouts. And, in fact, instructors mentioned that they could share and even project the screens of the simulator during some of the formal classes to demonstrate how to perform some key tasks to a group of electricians.

As enhancements, the reviewers suggested to include into the simulator a specific form to be filled by the electricians prior to do any task on the simulator to check the risks of the environment, on the network, and others, as this form is mandatory in the real life work.

5. CONCLUSION

This paper presented a multi-user, VR simulator to enhance the current trainings of electricians to work on the electric power distribution network. The proposed simulator offers a realistic scenario with components that are typical found on the distribution network, such as poles, low and medium voltage cables, fuse switches, isolators, and others. In addition, the proposed simulator provides some practices and situations that, usually, are not experienced in the current trainings. Therefore, given its potential, the proposed simulator can enhance the quality of the service of the electricians, promote safety as well as improve motivation of the electricians.

As future work, it is planned to add more complex exercises to the simulator and develop a management system to allow the instructors to organize the exercises in the simulator and analyze reports of the exercises performed by the electricians. Also, the authors are investigating gamification mechanics to improve the engagement (for example, implementing scores, rankings, badges, and others). In order to do that, a study is on going to identify the gamer style of the electricians (Kumar, et al., 2020) as well as the feasibility of some of the existing gamification mechanics listed by Mambo.io (Kanazawa, 2020) to the project.

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