Augmented Reality Applied to Reducing Risks in Work Safety in Electric Substations

Victor Menezes Rocha[1,2][a] and Saul Delabrida[3][b]

[1]Programa de Pós-Graduação em Instrumentação, Controle e Automação de Processos de Mineração (PROFICAM), Universidade Federal de Ouro Preto (UFOP) and Instituto Tecnológico Vale (ITV), Ouro Preto, Brazil

[2]Vale S.A., São Luís, Brazil

[3]Departamento de Computação (DECOM), Universidade Federal de Ouro Preto (UFOP), Ouro Preto, Brazil

Keywords: Electric Arc, Electric Shock, Electricity Hazards, Incident Energy, Industrial System.

Abstract: Activities that involve electric energy are among the most dangerous and most harmful to the worker they perform. Therefore, the general objective of this work is to develop a virtual reality application that simulates the use of augmented reality technology as a means of access guidance and safety instructions with electric substation operators/maintainers. For this purpose, a newsletter, a simplified 3D electrical substation was modelled for experimentation in virtual reality and, thus, to evaluate a user experience regarding the use of the prototype and define what are the main requirements that can be used for the construction of the final application.

1 INTRODUCTION

An industrial electrical substation is a physical arrangement of devices and equipment which the purpose is to modify the characteristics of electrical energy (voltage and current) to levels suitable for use in the machines that make up the production process and their subsequent distribution to them (Mamede Filho, 2005). During the performance of the maintenance and operation activities of these substations, the worker is exposed to several risks, among them that of electric shock, caused by accidental contact in energized parts, and that of the incident energy resulting from an electric arc (Queiroz & Senger, 2012).

In Brazil, according to the Brazilian Association for Awareness of the Dangers of Electricity (Abracopel), 7,040 accidents were recorded in the last 5 years (2015-2019). Its main causes are electric shock (60% or 4196 cases), short circuit fires (39% or 2764 cases) and lightning strikes (8% or 557 cases). However, despite the higher percentage involving domestic accidents and people not directly related to the electricity sector, 380 fatal accidents occurred with professional technicians or electricians (Abracopel, 2020).

In order to mitigate the risks associated with activities involving electricity, over the years there has been a constant evolution of safety procedures and industrial processes. Currently, the occupational safety management applied in electrical substations, is mainly based on the Regulatory Standard (NR) 10. This standard aims at safety in installations and services in electricity and provide for individual and collective control measures, safety in energized electrical installations, works involving high voltage and emergency situations (Brasil, 2019).

In turn, industrial processes are increasingly automated. With the advent of the fourth Industrial Revolution, a new form of more technological production has been achieved with the aim of increasing productivity, reducing costs and helping to control and make quick, efficient and well-qualified decisions.

In fact, what is sought is industrial automation based on the perfect relationship between the worker and Cyber-Physical Systems (CPS), embedded systems connected in a network, capable of managing physical processes and, through feedbacks, adapting new conditions in real time (Lee et al., 2015). In this way, the human being starts to assume the role of an entity with a higher level of control, redirecting his

[a] https://orcid.org/0000-0003-3216-0159
[b] https://orcid.org/0000-0002-8961-5313

Rocha, V. and Delabrida, S.
Augmented Reality Applied to Reducing Risks in Work Safety in Electric Substations.
DOI: 10.5220/0010454805330540
In *Proceedings of the 23rd International Conference on Enterprise Information Systems (ICEIS 2021) - Volume 2*, pages 533-540
ISBN: 978-989-758-509-8

efforts to situations that require higher lines of reasoning and more assertive decision-making.

Another point is the need for maintenance workers to keep the machines in perfect working order. In this scenario, Augmented Reality (AR) enters as another technology of this revolution, facilitating these works by providing more detailed information on the equipment and procedures to be performed. This technology is able to superimpose information and virtual objects on the real environment in which the user is. Thus, data, videos, images, photos, animations, texts and other computer-generated objects can be manipulated and appear integrated into the environment through a device, such as a smartphone, tablet or special glasses (Figure 1).

Figure 1: Augmented Reality applied to the context of electrical maintenance. Sources: https://www.mtitecnologia.com.br and https://se.com, respectively.

When associated with Virtual Reality (VR, advanced interface technology for computational applications, which allows the user to navigate and interact, in real time, with a virtual three-dimensional environment), AR has also been shown to be effective for conducting safer virtual training for workers (Hernández et al., 2016; Peng et al., 2018) Figure 2.

Figure 2: Representation of the visualization of objects and scenarios in Virtual Reality, Mixed Reality and Augmented Reality. Source: adapted from https://www.actimage.com.

The use of these last two technologies has been documented in the literature in actions of simulation, training and choice of more correct solutions in cases involving electric power substations (Antonijević et al., 2016; Torres Filho et al., 2013). However, most of the works have as object of study open-air substations belonging to the energy concessionaires (Hernández et al., 2016; Peng et al., 2018).

The purpose of this work is to carry out the proof of concept of the use of AR as support for industry workers, for that purpose an VR application was developed to simulate AR and the preliminary tests with the use of AR showed a reduction of approximately 90% in decision-making errors regarding improper access in risk areas.

The rest of this article is structured as: Section 2 describes the main risks that workers in the electricity sector are exposed to. Section 3 describes the work related to AR and VR in the electricity sector. Section 4 describes the experiment developed in VR simulating the use of AR. Section 5 the results obtained and problems identified in the prototype. Finally, Section 6, where we conclude this work.

2 PROBLEM STATEMENT

Electricity is an invisible risk, which does not emit visual or audible alerts to the individual, a fact that often lowers attention under operating conditions. Activities related to it, present risks to people's health and safety, and can cause everything from mild symptoms to immediate death. In the industry, several electrical risks can be identified, but the main ones are electric shock, electric arc and electromagnetism, the first two being more harmful to workers (Lourenço et al., 2007).

Electric shock is the pathophysiological effect resulting from the direct or indirect passage of external electrical current through a human's body. Depending on the exposure time, the victim's physical resistance, the intensity and path of the circulating electrical current, the physiological damage caused by the shock can bring more serious complications for the individual (Cadick et al., 2012).

The electric arc, is the passage of electric current through a non-conductive medium, such as air or oil, at high speeds (approximately 100 m/s). In general, it occurs due to the dielectric rupture of this medium, caused by the potential difference between the two materials and the proximity between them (Mamede Filho, 2005; Souza & Michaloski, 2017). The three main problems that increase the danger of the electric arc and are also capable of causing a person to die are:

a) Arc temperature - capable of reaching high temperatures and causing incurable burns;
b) Incident energy - amount of thermal energy (sudden fire) printed on a given surface and released during the formation of an electric arc. It can lead to the ignition of a worker's clothing, further increasing the risk of burns;

c) Pressure wave - developed through the explosive expansion of air and metals in the arc path. It is capable of breaking eardrums, crushing the lungs, causing head trauma, among other things.

Thus, the electric arc is an evident danger for both companies and workers. In companies, this phenomenon can cause total destruction of electrical panels and consequent loss of production, since their high temperatures and fused and vaporized metals can quickly reach other equipment and electrical circuits (Floyd et al., 2005). However, the risks are even greater for workers. People directly exposed to an electric arc event are subject to third degree burns, possible blindness, shock, explosion effects, hearing loss and instant death. In order to have an idea of the dimension of the risk of formation of an electric arc, Cadick et al. (2012) highlight that fatal burns can occur even at distances greater than 2.5m.

This work aims to study alternatives for workers performing inspection and maintenance activities in electric stations. Augmented reality and virtual reality were defined as the core technologies for the proposed solution. Next section describes related works.

3 RELATED WORK

This section describes works that use Augmented Reality (AR) or Virtual Reality (VR) in the industrial context.

A virtual environment is the representation through computer graphics of various elements of the real or abstract world, such as the dimension of an environment, lighting, size, shape and texture of an object, among others. In turn, Virtual Reality (VR) can be defined as the computational technique used to create these artificial environments in a realistic way, allowing its users to interact with it in real time (Kirner & Siscoutto, 2007; Laviola Júnior et al., 2017). In fact, through this human-machine interface, the user, in addition to being able to feel immersed in a three-dimensional environment, is also able to navigate, interact and modify its components in a natural and intuitive way (Cardoso et al., 2007; Lin et al., 2002; Wiederhold & Bouchard, 2014).

In view of its benefits, VR has been used in the most diverse areas of knowledge. In medicine, for example, its use ranges from aid in rehabilitation processes for patients, the simulation of complex situations, such as surgical tests, bone marrow collection, among other procedures, for fixing the protocol that should be adopted from a controlled environment (Brunner et al., 2016; Faria et al., 2016; Souza-Junior et al., 2020). In military training, VR, in turn, can generate a multitude of conflict simulations, which enable the exploration of the operator's limits and the correction of mistakes made so that there is no compromise on the mission to be triggered (Cuperschmid et al., 2015).

VR can be used in simulations of electrical substations to train teachers and graduate students, field operators and other support and maintenance professionals. As their users are not exposed to real equipment during the simulation, these scenarios may represent a decrease in the risk of accidents inherent to the learning and decision-making process. This technology has also been considered a powerful tool as visualization interfaces for energy system simulators and critical systems monitoring and control operations (Barata et al., 2015; Barcelos et al., 2013).

Still, Guangwei and Guan (2009), using a scene graph development approach for organizing and managing models in the realization of the Level of Detail (LOD), present a VR system design that allows operators to have a complete view of the process involving simulation, training and control of a substation's virtual environment. Finally, Silva et al. (2013), made adjustments to the Unity3D game engine to develop an application that would allow better monitoring and control of substations. In this work, Unity3D presented a good amount of resources and a satisfactory performance in relation to supporting scenes with large amounts of polygons; the LOD resource; the flexibility to choose programming languages (C #, JavaScript and Boo); the creation and use of packages with sufficiently generic functionalities that enable the reuse of functions; and the possibility of creating components to automate the scene editor.

If, on the one hand, virtual reality (VR) uses virtual objects and environments, on the other, augmented reality (AR) allows the visualization in an integrated way of a virtual element in the real world in which the user is; a real “augmented world” (Azuma, 1997; Mullen, 2011). Simplistically, Drascic and Milgram (1996) define AR as a technology capable of generating a real environment with graphic improvements. In other words, AR brings with it a new concept of visualization of information and images generated by computer, as it complements real environments instead of replacing them as in VR applications. Several AR technologies are available on the market, ranging from a simple smartphone camera, to more expensive options, such as AR glasses, which have semitransparent displays, coupled with a 3D camera for the projection of the virtual image.

By being able to generate a sense of dominance in the user, combining the presentation process and the possibility of interaction and manipulation of virtual objects, AR has become an increasingly immersive experience (Cardoso et al., 2014). In the last decade, several sectors have benefited from the development of its applications, such as educational, tourism, medical, design, geospatial, among others (Carmigniani et al., 2011; Engelke et al., 2015; Fiorentino et al., 2014; Gheisari et al., 2016; Mekni & Lemieux, 2014; Nee et al., 2012).

AR-based systems, for example, can support a variety of services, such as sending repair instructions via mobile devices or selecting parts in a warehouse, reducing travel costs and preventing maintenance rework from having to be misinterpreted (Bahrin et al., 2016). Still, new human-machine interfaces can be created from AR in the manufacture of applications and IT assets, displaying KPIs (Key Performance Indicator) and feedbacks about manufacturing processes in real time, in order to improve decision making (Gorecky et al., 2014).

Peres et al. (2018), for example, propose the application of AR for access to accumulated data and information in hydroelectric dams to be analyzed for cracks in the concrete, thus reducing the demand for mental workload in the employee. However, despite this new area of technology that has been discussing for some time in academic papers, Martinez et al. (2016) reviewing the literature on Industry 4.0, found no reference to augmented reality in the 531 abstracts of the analyzed publications, which indicates that this subject seems to be in an early stage of development.

In the context of electrical power substations, Barcelos et al. (2013), identifying the difficulty of graduates from Electrical Engineering courses in differentiating and classifying the elements of a substation, present a proposal for the use of AR in the visualization of these components as a way of complementing learning. For this, a protocol for creating an interactive catalog was suggested. Initially, virtual objects were created in 3D Studio Max® and, after the generation of their respective markers, the Unity 3D® game building engine and the NyARToolKit library enabled the synchronization between reading the catalog and viewing these objects in three dimensions. Also, the availability of AR glasses for students provided a greater experience of usability of the generated system and better immersion of the user. Finally, as suggested by Antonijević et al. (2016), AR can also be used as a support tool to increase the information visible to the user and contribute to the automation of electrical substations, using a simple smartphone. These authors developed an application based on QR markers and a combination of IEC61850 communication with AR, so that engineers received in real time the information necessary for maintenance and inspection of equipment from the process data recorded in the SCADA system.

4 PROPOSED SOLUTION

Based on the technologies and concepts presented in sections 2 and 3, a proof of concept of the use of AR is presented in this work. To this end, the aim was to develop a use case to be applied to the electrical maintenance team that involved the development of a prototype using Unity 3D, for a virtual environment (VR) similar to a physical arrangement of an industrial electrical substation in the context of simulation of maintenance activities on equipment contained in this room with (and without) the use of AR to read information from the equipment (RV simulating an AR environment); and evaluate the use and perceptions (user experience) by the maintenance execution teams, identifying advantages and problems arising from such a solution and verifying the team's propensity regarding the need to use (or not) the proposed solution for knowledge of details and information in real time of electrical installations. Therefore, the prototype to be developed should be able to:

1) Run on Android phones and simulated with the support of Virtual Reality Glass (VR Box) and Bluetooth Remote Controllers;
2) Represent as accurately as possible the physical arrangement of an electrical substation;
3) Allow the user to move everywhere within the scene and have a first-person camera perspective;
4) Establish virtual barriers to enable the correct positioning of the user in relation to the area of risk of electric arc and, if this exceeds the delimitation, show an alert indication on the screen;
5) Provide information about each electrical panel (data of current, voltage, active power and category of the panel) at the moment the user positioned himself in front of him;
6) Record the number of infractions committed during the execution of the pre-established task.

After application development, the use case was elaborated a 9 members the electrical maintenance teams (engineers and technicians) in Vale's operating areas in the ports of Tubarão (Vitória/ES) and Ponta da Madeira (São Luís/MA; Figures 3-4). The texts contained in figures 4 are in the official language of the developing country (Portuguese). Therefore, the experiment took place as follows:

1) Users were allowed to browse the virtual environment momentarily, through computers, before starting the test itself, in order to become familiar with the environment and with the movement controls.
2) Participants were asked to perform a field survey task of short-circuit current information on all panels contained in the fictitious substation and write it down on a clipboard. Assumptions were passed on to the participants and should be considered when performing the task:
   i. The information to be obtained (short circuit current) would be available on labels affixed to the front of each panel;
   ii. Electricians would be wearing flameproof clothing (Nomex), category 2, that is, minimum protection of 8 cal/cm2 (incident energy, according to ATPV index) as PPE;
   iii. The substation would not have an adjustment group, that is, there would be no mechanisms to reduce the incident energy of the panels, by changing /adjusting the operating times of the protection relays and/or using internal arc relays.
3) The experiment was carried out for the first time with the virtual Scenario 1 without the indication of the information on a virtual panel located to the left of the vision in the glasses, simulating the current method (without the use of AR). The expected behavior for this scenario would be for the electrician to refuse to do the activity. As he does not have prior knowledge of this information, he should adopt his right of refusal when considering the possibility of the panels presenting an incident energy higher than the category of his PPE (in this example, category 2). However, once he made the wrong decision to read the data, accessing the risk zone, an improper access counter was increased.
4) The experiment was repeated in a second virtual Scenario 2, with indication of the information, simulating the augmented reality method, informing the electrician about the data in advance, and allowing a safe decision not to violate the safe and adequate distance to your PPE (flameproof clothing, with a category appropriate to the incident energy of the panel).

A video with the view of the substation modeled in 3D can be accessed behind the address: https://youtu.be/ZXw46D-LZYM. In the video we are running the application on the second scenario (with RA). Therefore, it is not necessary for the user to access the unsafe area to view the main information on the panel. At the end of the video, it is shown that to read the label attached to the panel, it is necessary

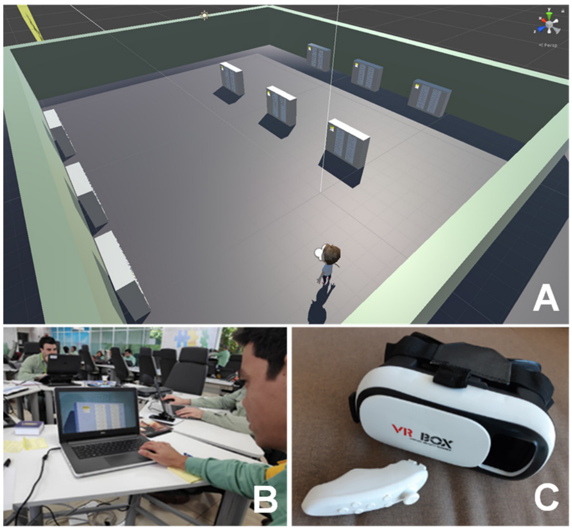

Figure 3: (A) Overview of the modeled substation; (B) Practical Reproduction of the Experiment in São Luís; (C) VR Box and Bluethooth Remote Controler glasses used for the experiment.

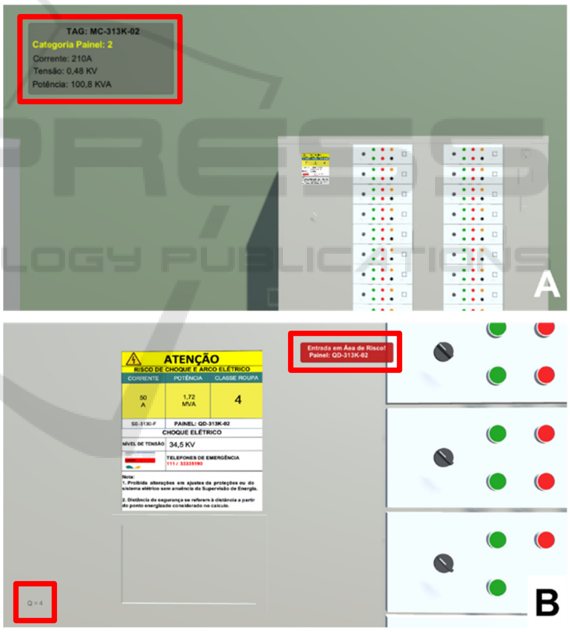

Figure 4: (A) Front view of a panel and tag with their respective information (with AR); (B) Front view of a panel and tag with their respective information. Image with the entry warning tag in the risk area and panel indication. Highlighted within the red square without filling is the accounting of errors made by the user when applying the tests.

to get closer, consequently exposing the work to risk. It is also possible to view the error/unsafe actions counter in the lower left corner of the screen.

5 RESULTS

After performing the tests, with the help of NASA TLX methodology, users were asked to evaluate the workload in both scenarios in terms of mental demand, physical demand, temporal demand, performance, effort and frustration. Thus, after compiling the results, it was found that the scenario without AR had a final score of 54,81, while the scenario with AR had a final score of 48,59. For this methodology, the lower the grade, the better the performance of the technology, since it requires less work demands, indicating a propensity of the team regarding the need to use the proposed solution. An analysis by arithmetic mean of the grades was also performed, confirming the data obtained previously (Table 1; Figure 5).

Table 1: Notes from Scenario 1 (without AR) and 2 (with AR), according to NASA TLX methodology and Arithmetic Average. Legend: WN - weighted note; SD - standard deviation.

			Scenario 1					Scenario 2				
Item	Score	Weight	Sum (score)	WN	Average	SD	Variance	Sum (score)	WN	Average	SD	Variance
Mental Demand	27	20%	63	12,60	7,00	1,12	1,25	44	8,80	4,89	2,71	7,36
Physical Demand	13	10%	48	4,62	5,33	2,50	6,25	26	2,50	2,89	1,69	2,86
Temporal Demand	27	20%	57	11,40	6,33	2,65	7,00	34	6,80	3,78	2,49	6,19
Overall Performance	33	24%	58	14,18	6,44	3,57	12,78	82	20,04	9,11	0,93	0,86
Effort	19	14%	55	7,74	6,11	3,26	10,61	54	7,60	6,00	3,50	12,25
Frustration Level	16	12%	36	4,27	4,00	3,28	10,75	24	2,84	2,67	1,66	2,75
	135			**54,81**	**35,21**				**48,58**	**29,34**		

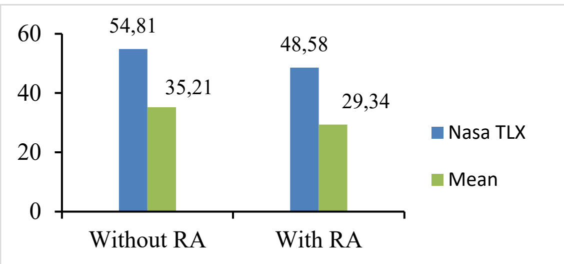

Figure 5: Comparison of the user's final grades (NASA TLX and arithmetic mean) in relation to the demands demanded during the execution of the experiment without and with the use of augmented reality.

Finally, the scenario with augmented reality showed an approximate reduction of 90% in errors of decision making regarding the improper access in risk areas (39 errors made in the scenario without AR and four with AR). This may indicate that the developed system has been successfully tested, confirming that, from its improvement, its application in real environments of electric power substations would be an effective solution to mitigate the risks associated with the activities carried out in it. However, two limitations were identified, which should be addressed in future projects: the low resolution of the video, which made it difficult to read the information with the use of cell phones; and the difficulty in recognizing by the user the model used to represent the electrical panels, being recommended the adoption of market design standards and/or the substation to be implemented the technology, so that users feel familiar with the interfaces.

6 CONCLUSIONS

This work evaluated augmented reality as a feature to support the workers in the industry field. Our focus is to provide a friendly user interface in hazardous environments. In this case, we evaluated the human operation of electric panels.

We also have used a virtual reality environment for stakeholders' experience. This strategy allowed us to understand the real application's best requirements and reduced the time spent developing the real application. Our methodology also reduces the need to access the hazardous environment.

The developed prototype was experimented by application stakeholders. Our findings demonstrate that the system is a feasible alternative to reduce and emit alert to workers in the field. Finally, as indirect advantages of using this technology, we can highlight the increase in the productivity of the teams, through a quick return of information and performance in the maintenance process, increase in the perception of information reliability, elimination of human errors in the collection / reading of data and reducing the level of stress of workers in making decisions that involve their safety. Then, with the lessons learned in this experiment, a real augmented reality system (not VR) is being developed for future user evaluation.

ACKNOWLEDGEMENTS

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) – Finance Code 001, the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPQ), the Fundação De Amparo a Pesquisa Do Estado De Minas Gerais - FAPEMIG grant code APQ-01331-18, the Instituto Tecnológico Vale (ITV), the Universidade Federal de Ouro Preto (UFOP) and Vale S.A.

REFERENCES

Abracopel. (2020). *Anuário estatístico de acidentes de origem elétrica 2020 – ano base 2019*. Retrieved 15/05/2020 from http://mkt.abracopel.org.br/w/jereXjpe7Bymp6sjCShe94-3-125e!uid?egu=o0n9udpuxa0w8pau

Antonijević, M., Sučić, S., & Keserica, H. (2016). Augmented reality for substation automation by utilizing IEC 61850 communication. 39th International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO), Opatija, Croatia.

Azuma, R. T. (1997). A survey of augmented reality. *Presence: Teleoperators and Virtual Environments*, *6*(4), 355-385. https://doi.org/10.1162/pres.1997.6.4.355

Bahrin, M. A. K., Othman, M. F., Azli, N. H. N., & Talib, M. F. (2016). Industry 4.0: A review on industrial automation and robotic. *Jurnal Teknologi*, *78*(6-13).

Barata, P. N. A., Ribeiro Filho, M., & Nunes, M. V. A. (2015). Consolidating learning in power systems: Virtual reality applied to the study of the operation of electric power transformers. *IEEE Transactions on Education*, *58*(4), 255-261. https://doi.org/10.1109/TE.2015.2393842

Barcelos, M. A., dos Santos Peres, I. C., Mattioli, L. R., Júnior, E. L., & Cardoso, A. (2013). Uso de realidade aumentada na visualização de componentes de subestações de energia elétrica. XI Conferência de Estudos em Engenharia Elétrica, Minas Gerais, Brasil.

Brasil, M. d. T. (2019). NR-10 - Segurança em instalações e serviços em eletricidade. https://enit.trabalho.gov.br/portal/images/Arquivos_SST/SST_NR/NR-10.pdf

Brunner, I., Skouen, J. S., Hofstad, H., Aßmuss, J., Becker, F., Pallesen, H., Thijs, L., & Verheyden, G. (2016). Is upper limb virtual reality training more intensive than conventional training for patients in the subacute phase after stroke? An analysis of treatment intensity and content. *BMC neurology*, *16*(1), 219. https://doi.org/10.1186/s12883-016-0740-y

Cadick, J., Neitzel, D. K., & Capelli-Schellpfeffer, M. (2012). *Electrical safety handbook* (4 ed.). McGraw-Hill.

Cardoso, A., Júnior, E. A. L., & A Barcelos, M. (2014). Ferramentas de apoio ao ensino de componentes de subestações de energia elétrica com uso de realidade virtual e aumentada. *Iniciação-Revista de Iniciação Científica, Tecnológica e Artística*, *4*(3).

Cardoso, A., Kirner, C., Júnior, E. L., & Kelner, J. (2007). Tecnologias e ferramentas para o desenvolvimento de sistemas de realidade virtual e aumentada. *Editora Universitária UFPE*, 1-19.

Carmigniani, J., Furht, B., Anisetti, M., Ceravolo, P., Damiani, E., & Ivkovic, M. (2011). Augmented reality technologies, systems and applications. *51*(1), 341-377. https://doi.org/10.1007/s11042-010-0660-6

Cuperschmid, A. R. M., Amorim, J. A., Matos, C. E. A., & Einstein, A. (2015). Uso de Realidade Aumentada para o Treinamento Militar. *Revista Militar de Ciência e Tecnologia*, *3*, 5 - 17.

Drascic, D., & Milgram, P. (1996). Perceptual issues in augmented reality. Stereoscopic displays and virtual reality systems III, San Jose, CA, United States.

Engelke, T., Keil, J., Rojtberg, P., Wientapper, F., Schmitt, M., & Bockholt, U. (2015). Content first: a concept for industrial augmented reality maintenance applications using mobile devices. 6th ACM Multimedia Systems Conference, Portland, EUA.

Faria, A. L., Andrade, A., Soares, L., & i Badia, S. B. (2016). Benefits of virtual reality based cognitive rehabilitation through simulated activities of daily living: a randomized controlled trial with stroke patients. *Journal of Neuroengineering and Rehabilitation*, *13*(1), 96. https://doi.org/10.1186/s12984-016-0204-z

Fiorentino, M., Uva, A. E., Gattullo, M., Debernardis, S., & Monno, G. (2014). Augmented reality on large screen for interactive maintenance instructions. *Computers in Industry*, *65*(2), 270-278.

Floyd, H. L., Doan, D., Wu, C., & Lovasic, S. (2005). Arc flash hazards and electrical safety program implementation. Fourtieth IAS Annual Meeting. Conference Record of the 2005 Industry Applications Conference, 2005., Kowloon, Hong Kong, China.

Gheisari, M., Sabzevar, M. F., Chen, P., & Irizarry, J. (2016). An augmented panoramic environment to access building information on a construction site. 52nd ASC Annual International Conference Proceedings, Provo, Utah, EUA.

Gorecky, D., Schmitt, M., Loskyll, M., & Zühlke, D. (2014). Human-machine-interaction in the industry 4.0 era. 2014 12th IEEE international conference on industrial informatics (INDIN), Porto Alegre, RS, Brazil.

Guangwei, Y., & Guan, Z. (2009). Scene graph organization and rendering in 3D substation simulation system. 2009 Asia-Pacific Power and Energy Engineering Conference, Wuhan, China.

Hernández, Y., Pérez-Ramírez, M., Ramírez, W. I., Ayala, E. N., & Ontiveros-Hernández, N. (2016). Architecture of an Intelligent Training System based on Virtual Environments for Electricity Distribution Substations.

Res. Comput. Sci., *129*, 63-70. https://doi.org/10.13053/rcs-129-1-7

Kirner, C., & Siscoutto, R. (2007). Realidade virtual e aumentada: conceitos, projeto e aplicações. IX Symposium on Virtual and Augmented Reality, Petrópolis, RJ, Brasil.

Laviola Júnior, J. J., Kruijff, E., McMahan, R. P., Bowman, D., & Poupyrev, I. P. (2017). *3D user interfaces: theory and practice*. Addison-Wesley.

Lee, J., Bagheri, B., & Kao, H.-A. (2015). A cyber-physical systems architecture for industry 4.0-based manufacturing systems. *3*, 18-23. https://doi.org/10.1016/j.mfglet.2014.12.001

Lin, F., Ye, L., Duffy, V. G., & Su, C.-J. (2002). Developing virtual environments for industrial training. *Information Sciences*, *140*(1-2), 153-170. https://doi.org/10.1016/S0020-0255(01)00185-2

Lourenço, S. R., Silva, T. A. F., & da Silva Filho, S. C. (2007). Um estudo sobre os efeitos da eletricidade no corpo humano sob a égide da saúde e segurança do trabalho. *5*(1), 135-143. https://doi.org/10.5585/exacta.v5i1.1043

Mamede Filho, J. (2005). *Manual de Equipamentos Elétricos* (3 ed.). Grupo Gen-LTC.

Martinez, F., Jirsak, P., & Lorenc, M. (2016). Industry 4.0. The end lean management? 10th International Days of Statistics Economics, Prague, Czech Republic.

Mekni, M., & Lemieux, A. (2014). Augmented reality: Applications, challenges and future trends. *Applied Computational Science*, *20*, 205-214.

Mullen, T. (2011). *Prototyping augmented reality*. John Wiley & Sons.

Nee, A. Y., Ong, S., Chryssolouris, G., & Mourtzis, D. (2012). Augmented reality applications in design and manufacturing. *61*(2), 657-679.

Peng, Y., Yu, G., Ni, W., Lv, Z., Jiang, Y., & Chen, J. (2018). Design and development of intelligent operation and maintenance training system for substation based on augmented reality. 2017 Chinese Automation Congress (CAC), Jinan, China.

Peres, F. F., Scheer, S., & de Faria, É. F. (2018). A taxonomy of tasks in dam cracks surveillance for augmented reality application. *International Journal of Advanced Engineering Research Science*, *5*(10). https://doi.org/10.22161/ijaers.5.10.24

Queiroz, A. R. S., & Senger, E. C. (2012). *A natureza e os riscos do arco elétrico, EPIs e proteção contra arco elétrico.* Retrieved 10/01/2020 from https://www.osetoreletrico.com.br/capitulo-i-a-natureza-e-os-riscos-do-arco-eletrico/

Silva, A. C., Mattioli, L. R., Peres, I. C. S., Cardoso, A., do Prado, P. R. M., & Newton, J. (2013). Uso da Engine de Jogos Unity3D para Sistemas de Realidade Virtual Aplicado a Monitoramento e Controle de Subestações de Energia Elétrica. https://doi.org/10.13140/2.1.1696.0807

Souza-Junior, V. D. D., Mendes, I. A. C., Tori, R., Marques, L. P., Mashuda, F. K. K., Hirano, L. A. F., & Godoy, S. D. (2020). VIDA-Enfermagem v1. 0: realidade virtual imersiva na coleta de sangue a vácuo em adulto. *Revista Latino-Americana de Enfermagem*, *28*. https://doi.org/10.1590/1518-8345.3685.3263

Souza, S., & Michaloski, A. O. (2017). A Norma Regulamentadora Nº10 e a aplicação em instalações elétricas e seus entornos. *Revista Técnico-Científica*, *5*(6), 145-152.

Torres Filho, F., Vieira, M. d. F. Q., & Soares, W. L. F. (2013). Processo para o desenvolvimento de cenários de treinamento para ambientes Virtuais 3D. *Simpósio Brasileiro de Automação Inteligente*.

Wiederhold, B. K., & Bouchard, S. (2014). *Advances in virtual reality and anxiety disorders*. Springer.