An Immersive Training Approach for Induction Motor Fault Detection and Troubleshooting

Gustavo Caiza[1], Marco Riofrio-Morales[2], Angel Robalino-Lopez[3], Orlando R. Toscano[4], Marcelo V. Garcia[2,5](✉), and Jose E. Naranjo[2]

[1] Universidad Politecnica Salesiana, UPS, 170146 Quito, Ecuador
gcaiza@ups.edu.ec

[2] Universidad Tecnica de Ambato, UTA, 180103 Ambato, Ecuador
{mriofrio3650,mv.garcia,jnaranjo0463}@uta.edu.ec

[3] Instituto Superior Tecnológico Victoria Vásconez Cuvi, ISTVVC, 050103 Latacunga, Ecuador
arobalino@institutovvc.edu.ec

[4] Instituto Superior Tecnológico España, ISTE, 180103 Ambato, Ecuador
orlandor.toscanor@iste.edu.ec

[5] University of Basque Country, UPV/EHU, 48013 Bilbao, Spain
mgarcia294@ehu.eus

Abstract. Industry 4.0 has gained drive in the last few years since most companies at the industrial level need to update and optimize their production chain. Restructuring their processes and improving their human resources skills is imperative if they want to remain competitive. This research presents the development of a virtual reality system for induction motor troubleshooting training. Two sample groups were taken as references. The first one was trained with the VR system, while the second group worked with a conventional methodology. With the use of the proposed system, there was a time reduction of 57.73%. In terms of knowledge acquisition, it was possible to confirm, with a p-value lower than 0.05, that the VR system is more efficient than the conventional methodology. Finally, the system's usability was evaluated utilizing the System Usability Scale (SUS), obtaining an average value of 73.33.

Keywords: Optimization · Industrial training · Virtual reality · Induction motors

1 Introduction

The development of personnel knowledge should progress along with innovation. It is fundamental to improve the productive chain of an organization. As of now, it is new to join preparing with virtual instruments; this implies diminishing expenses and ensuring the learning of the data bestowed to the staff. The focal responsibility of virtual preparing is to produce quick and simple to utilize solutions for human resources [3,6].

L. T. De Paolis et al. (Eds.): AVR 2021, LNCS 12980, pp. 499–510, 2021.
https://doi.org/10.1007/978-3-030-87595-4_36

The 4.0 revolution allows this sort of innovation, consequently permitting an efficient management. Most businesses have been compelled to enter this new time to get more effective creation strategies. The main tools inside this era are VR, augmented reality (AR) and extended reality (XR), utilized for staff preparing.

The main recipients of this innovation are the raw materials' industry, which allows for automatic control of the process. These technologies are said to have a wide range of uses, from educational, military, medical to industrial machinery maintenance [1].

The health crisis and the monetary emergency that the world is encountering make innovation a definitive factor in addressing these challenges. On an industrial level, employers also have a serious impact, trying to ensure employee health, avoid physical contact and seek new ways to implement robotized work. Create products for the industrial sector using virtual platforms and applications is a means to neutralize the damage caused by the pandemic [13].

It is clear that with the application of virtual techniques, the frequency of work and interpersonal relationships will change [11]. The current and future alternative is virtual reality. This is to avoid the industrial environment and to maintain human integrity. It is an option available in all industrial manufacturing processes [14].

Likewise, technological advancements make it possible for us to apply virtual fields to all industries and surprisingly to people's everyday lives. Similarly, this is a major factor as many companies have adopted this model to train all processes in the industrial sector. The main benefit by adopting virtual reality is improved performance in industrial projects. In addition, it is an element that seeks continuous improvement over other organizations and an industrial competitive advantage. [4,14].

In this article, we will explain the development of VR system for fault detection training of three-phase motors and its comparison with conventional training systems. This system was developed using the Unity 3D graphics engine and Blender.

This article is divided into six sections, including the introduction. In Sect. 2, the objectives of the study are detailed. In Sect. 3, the developed interfaces are explained, while in Sect. 4, the usability evaluation is deployed. In Sect. 5, the results are discussed; and, in Sect. 6, the conclusions and future works are studied.

2 Case of Study

This study compares two types of training in fault detection and repair of three-phase electric motors. The first is based on lessons that apply as usual in the health crisis we are boldly facing. A virtual classroom with videos, slides and video calling software. The second uses an immersive VR app. The app uses interactive content and sensors to provide users with a fully immersive experience. See Fig. 1.

Due to the high probability of failure with this type of engine, the failures in this study are the most common and easy to detect and are described below.

- **Broken Bars:** It reduces the smooth operation efficiency of the induction motor. The problem starts with a broken bar and if not fixed in time will cause more rotor bars to break. Therefore, these machines require regular maintenance [8].
- **Inter-turn short circuits:** They are caused by damage to the insulating coating of the windings. This can also affect the entire coil and adjacent coils. Mechanical stress, high current or thermal shock are some causes of insulation. When this damage occurs, it will cause vibration problems in the machine and cause serious magnetic field damage [5].

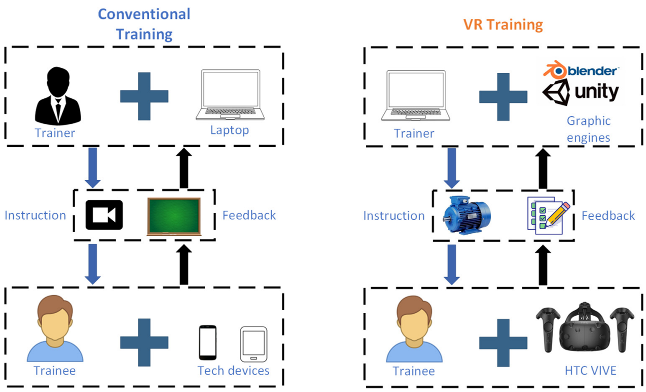


Fig. 1. Conventional and VR training

3 Interactive System Design

The graphic environment limits the space in which the user develops and learns to identify possible faults in the electric motors. Here the Unity 3D graphics engine and Blender design software were used. An interactive interface was also created with the HMD and HTC VIVE command.

In Fig. 2, it can be identified that the VR system consists of three modules. i) Overview: Learn the technical concepts of three-phase asynchronous motors in a general presentation. This was done through the video. ii) Engine failures: Allows the user to recognize the failures caused by bar breakage or short circuit and learn how to fix them. iii) Test: Required to evaluate the knowledge acquired by the apprentice.

When the system is started, users will be immersed in a mechanical workshop, perfecting their presence and feeling themselves in an environment useful for industrial learning. Here they will be presented with a menu of options where they can choose to start the workout or exit the system. See Fig. 3. When the user agrees to start training, a video will be displayed explaining the basics of the induction motor, its parts, and the application. When finish the video, the button to move on to the next scene is activated. This can be appreciated in Fig. 4.

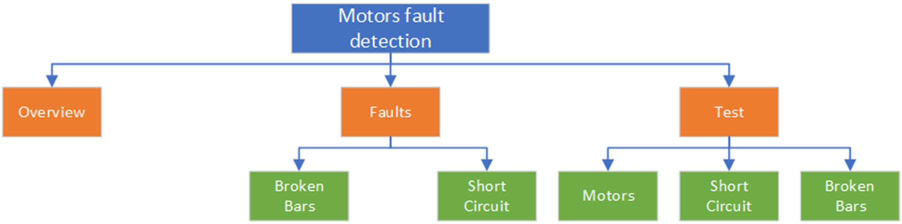


Fig. 2. System block diagram

Fig. 3. Options menu

In Fig. 5, the rated data of the motor is running and the phase signal of the oscilloscope is displayed. The first mistake users have to learn is broken bars. We also simulated the characteristic sound of this engine to help users get used to a real environment. With this interface, the learner can use buttons to view on a map the signal difference between a non-faulty motor and a faulted motor.

There is auditory feedback in this scene, which explains that the amplitude in the frequency range of 75 to 110 Hz decreases to lower values of −40 dBV compared to a standard signal. On the other hand, it is also taught that there is an increase in amplitude in the frequency range from 100 to 110 Hz. Finally, it is established that another characteristic of this type of failure is the creation of lateral peaks near 70, 40 and 50 Hz with oscillating amplitudes around −10 dbV. See Fig. 6.

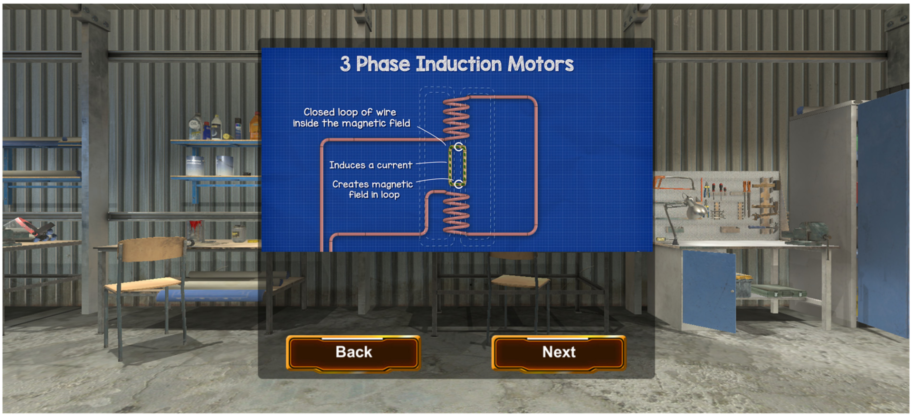


Fig. 4. Tutorial

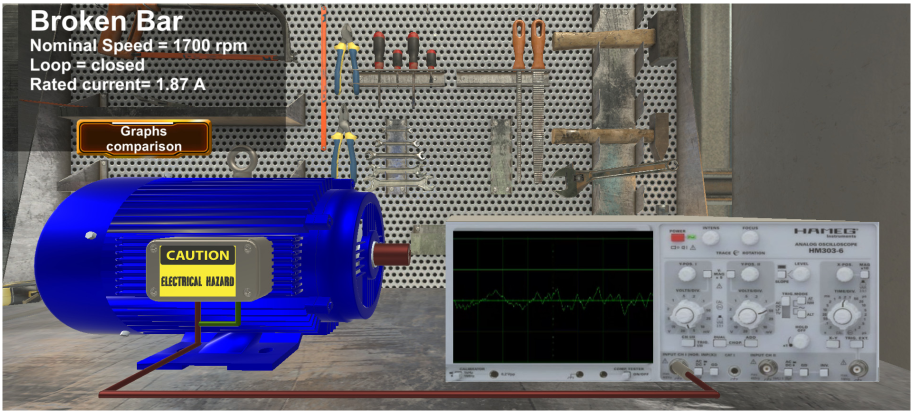


Fig. 5. Broken bars fault

When the user understands this information, the disassembled motor will be displayed. That is, the case and stator are not visible. A rotating red arrow identifies visible physical damage and draw students' attention. The above described can be seen in Fig. 7. The user is then trained on how to repair it. We chose to braze here because it is the most common way to repair minor damage in small rotor bars. When the repair is complete, the damage is gone and the apprentice can move on to the next fault. See Fig. 8.

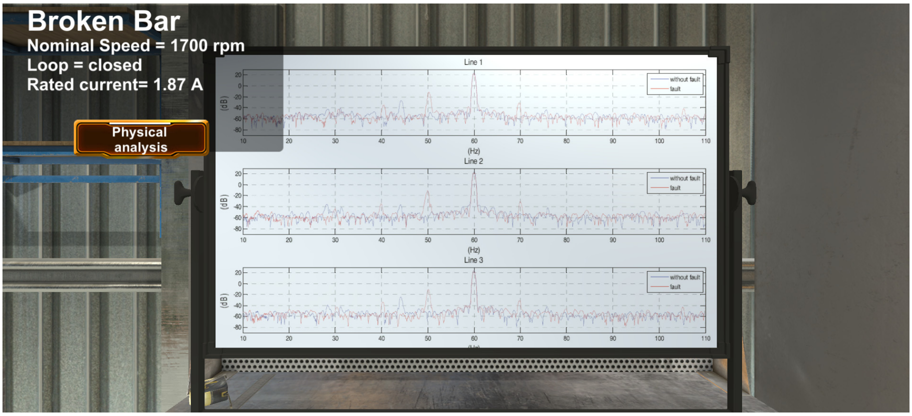


Fig. 6. Broken bars: graphs comparison

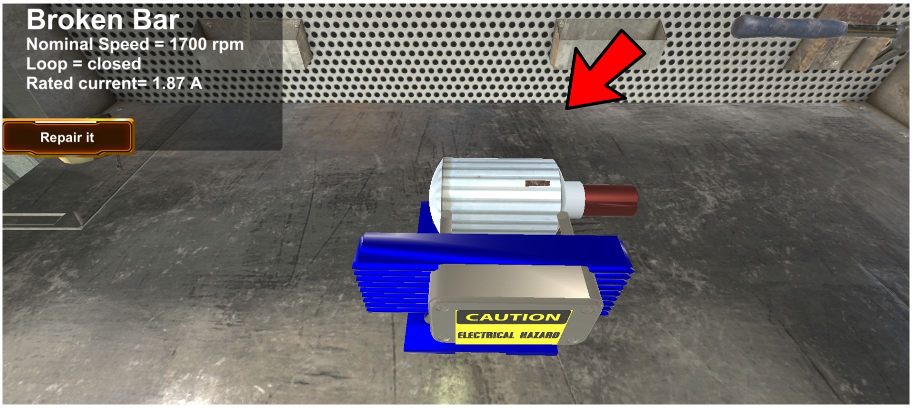


Fig. 7. Broken bars fault: physical damage

The scenes developed for the inter-turn short circuits failure are similar. The rated motor data displayed on the screen is different, so the actual status of this fault can be created. In Fig. 9, the user will be able to learn that, in phase 3, there is a relatively small increase of 0.53 dBv in the frequency 300 Hz. In phase 1, the spectral signal moves 11 dBv above the signal without failures. Finally, in the three phases, it can be seen that 180 Hz, the signal spectrum increases 23 dBv above the noise level [2].

Finally, a questionnaire of 10 multiple-choice questions was set up to evaluate the knowledge acquired by each user. Four are for understanding bars breakage failures, four are for short circuits between turns, and two are for a general understanding of three-phase electric motors. Each question has three options, only one of which is appropriate. To ensure the reliability of the response, it is recorded and cannot be changed. In Fig. 10, it is shown that after finishing the

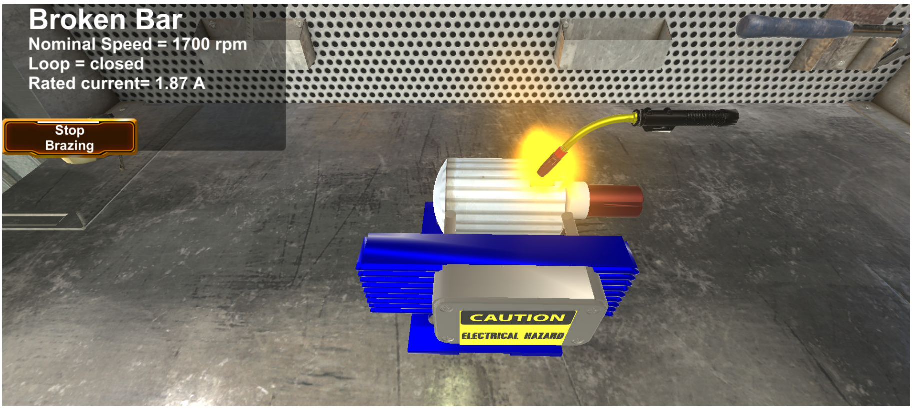


Fig. 8. Broken bars fault: brazing process

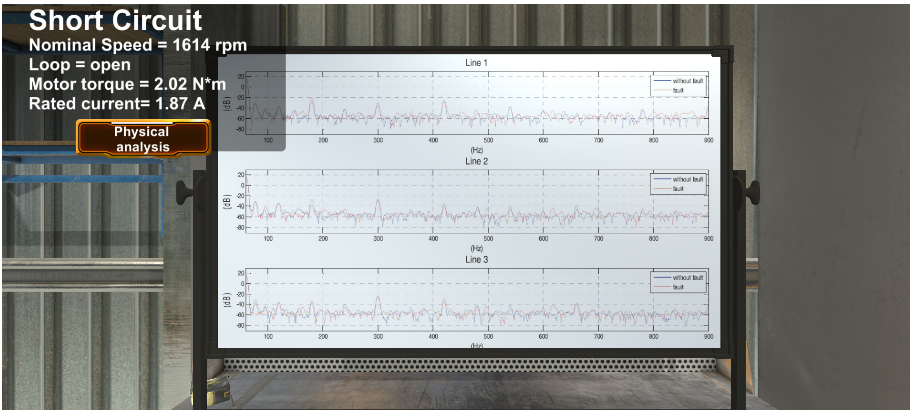


Fig. 9. Short circuit: graphs comparison

test a scene with all the test information will be generated, i.e., username, time and score.

4 System Usability Scale

Scores from 0 to 100 determine the efficiency of the developed system. Products with more than 80 are excellent and are rated A. Systems rated from 70 to 80 are considered acceptable and rated B. A score from 50 to 70 indicates a poor system and are rated C. Finally, systems with a score below 50 rated D [9].

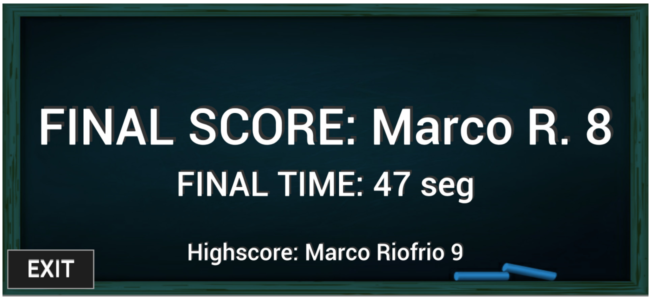


Fig. 10. Test feedback

Each of the even-numbered questions is scored by subtracting the user's score from 5, that is (5 − Y). Instead, subtracting one from the user-generated score (Y − 1) is performed for odd-numbered questions. To determine the final score, add the number of positive and negative questions and multiply by 2.5 to produce the final result regarding the usability of the VR system [12].

5 Results

To achieve the goals of this study, the experiment was designed with the participation of students from Ambato in Ecuador, who have a basic knowledge of electronics. The sample consisted of two groups of 15 participants each. A control group and an experimental group were created.

Figure 11 shows that in traditional training, 50% of the points are concentrated on 6 or higher, except for a score of 3. The virtual reality-based method states that 50% of the scores are 8 or higher.

To statistically test the effectiveness of VR training, T student is used and is based on two assumptions: i) H_0 There isn't a significant difference between traditional training and VR training; and ii) H_1 There is a significant difference between traditional training and VR training. The confidence level was $\alpha = 5\%$.

The ShapiroWilk test determines the normality of observations for samples containing less than 30 data. The significance values for regular training and VR were 0.908 and 0.934. This verifies that there is a normal distribution. A Levene test with a significance value of 0.36 was performed to determine the equivalence of the variances.

With these parameters calculated, the significance value was obtained (0.000003). Below 0.05, this value is more likely to reject H0 and accept H1, VR training is more effective than traditional training, with solid knowledge, information retention and proper understanding of the procedures presented.

Meanwhile, each of the two induction motor maintenance training courses have been timed to determine if there is resource optimization. Traditional instruction was given to the control group for a fixed period of 60 min. During this phase, the professional's presentation, proposed modules, and the test were

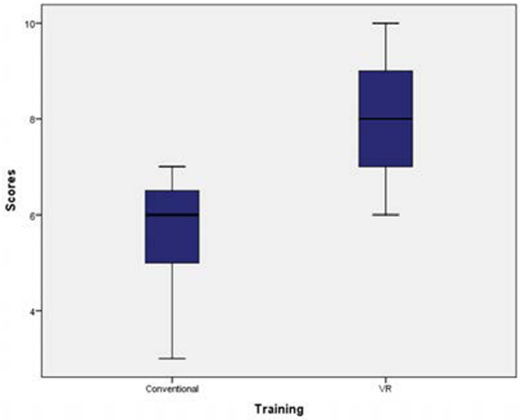


Fig. 11. Conventional and VR scores

considered. In contrast, the virtual reality training was conducted at different times. The total experience time lasted an average of 25 min 36 s.

In Fig. 12 it can be seen that learning in VR can save a lot of time. We found that the optimized time was 57.73% compared to regular training. This analysis shows that learning through Industry 4.0 help to gain better understanding. In conclusion, induction motor maintenance operators can gain more experience and learn through this technology. On the other hand, the optimization of resources is essential to reduce costs and improve industry efficiency.

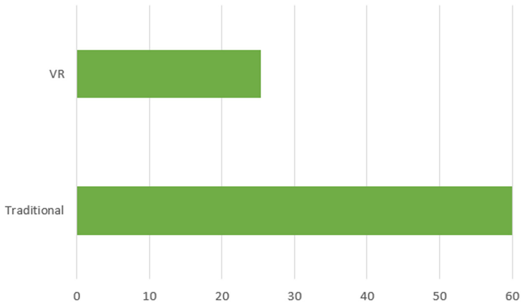


Fig. 12. VR vs conventional training time

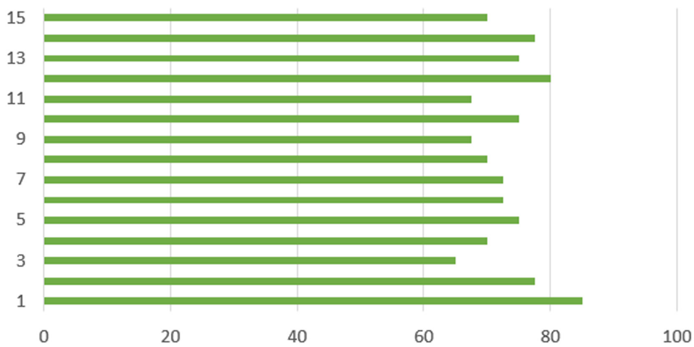
As with other studies, acceptance assessment was performed through a survey that followed the guidelines presented by SUS [7,10]. The following items were included in the survey:

1. I think that I would like to use this VR system frequently.
2. I found the VR system unnecessarily complex.

3. I thought the VR system was easy to use.
4. I think that I would need the support of a technical person to be able to use this VR system.
5. I found the various functions in this VR system were well integrated.
6. I thought there was too much inconsistency in this VR system.
7. I would imagine that most people would learn to use this VR system very quickly.
8. I found the VR system very cumbersome to use.
9. I felt very confident using the VR system.
10. I needed to learn a lot of things before I could get going with this VR system.

The second group answered 10 statements using the Likert scale. The average value obtained was 73.33. Due to the range of the final grade, it can be said that it is a friendly and intuitive system.

In Fig. 13, the participants' grades are deployed. Users find every module of the system appropriate. According to the SUS, induction motor troubleshooting training is accepted by 12 people. On the other hand, the other three people scored below 70 points, so they claim that the VR system was not easy to use.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Scores	85	77.5	65	70	75	72.5	72.5	70	67.5	75	67.5	80	75	77.5	70

Fig. 13. SUS scores

6 Conclusions and Future Work

A VR system has been developed for the training in terms of induction motor troubleshooting. The SUS methodology has shown that users consider the system suitable. However, since this is the first version of the model, there are still factors to consider, such as system interaction, responsiveness, and robustness. It is also recommended to use other methodologies to evaluate the usability of the system, as well as to follow specific guidelines to create the scenarios efficiently.

Acknowledgements. The authors recognize the supported bringing by Universidad Tecnica de Ambato (UTA) and their Research and Development Department (DIDE) under project CONIN-P-256-2019.

References

1. Baygin, M., Karakose, M., Akin, E.: ITHET 2016: 2016 15th International Conference on Information Technology Based Higher Education and Training (ITHET): 8–10 September 2016, Istanbul, Turkey. Institut of Electrical and Electronics Engineering (2016)
2. Caiza, G., Garcia, C.A., Naranjo, J.E., Garcia, M.V.: Assessment of engineering techniques for failures simulation in induction motors using numerical tool, pp. 307–319 (2021)
3. Cervera, M., Grandon, N., Rivera, M., Besoain, F.: Improving the selection of IQF raspberries in processing lines: A Virtual Reality approach for training and selecting personnel. In: 2018 IEEE Biennial Congress of Argentina, ARGENCON 2018, pp. 1–7 (2019)
4. Davila Delgado, J.M., Oyedele, L., Beach, T., Demian, P.: Augmented and virtual reality in construction: drivers and limitations for industry adoption. J. Constr. Eng. Manage. **146**(7), 04020079 (2020)
5. Fireteanu, V., Constantin, A.I., Leconte, V., Lombard, P.: Analysis of the evolution of stator short-circuit and rotor bar breakage faults in a squirrel-cage induction motor. In: SPEEDAM 2018 - Proceedings: International Symposium on Power Electronics, Electrical Drives, Automation and Motion, pp. 190–195 (2018)
6. He, Q., Cheng, X., Cheng, Z.: A VR-based complex equipment maintenance training system. In: Proceedings - 2019 Chinese Automation Congress, CAC 2019, pp. 1741–1746 (2019)
7. Kim, S.U., Lee, K., Cho, J.H., Koo, K.C., Kim, S.B.: Toward an evaluation model of user experiences on virtual reality indoor bikes. Eur. Sci. J. **7881**(June), 1857–7881 (2017)
8. Maloma, E., Muteba, M., Nicolae, D.V.: Effect of rotor bar shape on the performance of three phase induction motors with broken rotor bars. In: Proceedings - 2017 International Conference on Optimization of Electrical and Electronic Equipment, OPTIM 2017 and 2017 International Aegean Conference on Electrical Machines and Power Electronics, ACEMP 2017, pp. 364–369 (2017)
9. Meldrum, D., Glennon, A., Herdman, S., Murray, D., McConn-Walsh, R.: Virtual reality rehabilitation of balance: assessment of the usability of the Nintendo Wii & #x00AE; fit plus. Disabil. Rehabil. Assistive Technol. **7**(3), 205–210 (2012)
10. Naranjo, J., Urrutia Urrutia, F., Garcia, M., Gallardo-Cardenas, F., Franklin, T., Lozada-Martinez, E.: User experience evaluation of an interactive virtual reality-based system for upper limb rehabilitation. In: 2019 6th International Conference on eDemocracy and eGovernment, ICEDEG 2019 (2019)
11. Rozo-García, F.: Revisión de las tecnologías presentes en la industria 4.0. Revista UIS Ingenierías **19**(2), 177–191 (2020)
12. Sharfina, Z., Santoso, H.B.: An Indonesian adaptation of the system usability scale (SUS). 2016 International Conference on Advanced Computer Science and Information Systems, ICACSIS 2016, pp. 145–148 (2017)

13. Urbina Pérez, M.G., Mecalco Reyes, J., Muñoz Herrera, C.A., Cruz Silva, S.P.: Las fortalezas y debilidades de los ambientes virtuales/digitales en crisis sanitarias; caso de estudio Covid-19 en México (November), pp. 1–7 (2021)
14. Wang, C.: Research on panoramic image processing technology based on virtual reality technology. In: Proceedings - 2019 International Conference on Virtual Reality and Intelligent Systems, ICVRIS 2019, pp. 55–58 (2019)