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Virtual Reality System for training in the detection and solution of failures in induction motors.

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Abstract

The changing industrial world in which we find ourselves has forced companies to evolve technologically, restructuring their processes and improving their human resources skills. The acceptance by management of a fourth industrial revolution in transition to a fifth has led them to look for an economical way to stay updated and with the necessary skills to optimize their production chain. This work presents the development of virtual reality (VR) system for training in detecting faults in three-phase electric motors. A sample of 30 people was used, homogeneously divided into a control group and an experimental group. To evaluate the VR systems usability, the System Usability Scale (SUS) was used, obtaining an average value of 73.33, classifying the system as efficient for the proposed task. On the other hand, in terms of time and knowledge retention, the performance of this system was compared with the execution of a conventional one. For the training time, an optimization of 57.73% was obtained, while through a p-value of 0.000003, it was confirmed that this VR system provides a novel teaching methodology for the instruction and retention of technical knowledge.

Keywords: Virtual reality; Industrial training; Optimization; System Usability Scale (SUS); Induction Motors

1. Introduction

The learning of human resources must advance together with technology. They are essential to optimize the productive chain of a company or industry. At present, it is new to incorporate training with virtual mechanisms; this means reducing costs and guaranteeing the learning of the information imparted to the personnel. The central commitment of virtual training is to generate fast and easy-to-use solutions for human resources (Cervera et al., 2019; He et al., 2019).

Industrial revolution 4.0 promotes this type of technology, thus allowing the entry of information and efficient resource management. Most industries have been forced to enter this new era in order to obtain more efficient production techniques. The digital tools within this fourth industrial revolution are VR and augmented reality (AR), used for staff training.

The primary beneficiaries of this technology are the goods industries since it allows the automated management of their processes. By having such a wide field of utilisation, it has been seen that these technologies have applications from education, military and medicine to the maintenance of machinery at an industrial level (Baygin, Mehmet; Karakose Mehmet; Akin, 2016).

The health emergency and the economic crisis that the world is experiencing make technology a decisive factor in overcoming these difficulties. At an industrial level, there are also severe effects since employers, ensuring the health of their employees, seek to avoid physical contact and investigate new ways of performing automated work. Virtual applications and platforms are used to create products for the industrial area, which is a way to counteract the damages caused by the pandemic (Urbina Pérez et al., 2021).

It is evident that with the application of virtual procedures in the industrial environment, changes are forged in the working frequency and interpersonal relationships (Rozo-García, 2020). A technological alternative to the present and future is VR since it avoids the industrial environment and maintains the integrity of people. It is an available option in all processes of industrial production (Wang, 2019).

Similarly, the continuous progress of technology allows the application of virtual fields in all industries and even in people's daily lives. It is a tool that helps to avoid accidents since it allows to obtain a virtual didactic automated handling. Likewise, since many companies have adopted this model to carry out training in all the industrial sector processes, it is a preponderant factor. One of the main advantages adopted with the application of VR is better performance in industrial projects. Besides, it is a factor that seeks continuous improvement and competitive industrial advantage over other organizations (Wang, 2019; Davila Delgado et al., 2020).

As described in previous paragraphs, this article presents the development of a VR system for training in the detection of failures of three-phase motors with squirrel-cage rotor, as well as its comparison with a conventional training system. The system has been developed using the Unity 3D graphics engine and Blender. The HMD and HTC VIVE controls have also been integrated.

This article is divided into eight sections, including the introduction. Section 2, presents a brief description of works similar to the research proposal, in 3, the objectives of the study are delimited. In section 4, the development and usefulness of the interfaces are described, while in section 5, the methodology used for the usability evaluation is shown. Section 6, defines the selected sample, and the usability questions asked. In 7, the obtained results are discussed; and, in 8, the conclusions and future works are displayed.

2. State of the art

VR technology is increasingly used in industrial processes. The fourth industrial revolution is essential since it allows optimizing the training of human resources. This generates efficiency in the time and cost that the industries budget. For this reason, several researchers have made VR simulators to optimize the productive chain of corporations. Some works are cited below.

Lacko (Lacko, 2020), in his study, shows the use of VR to provide health and safety training for industries. He focuses on solving possible failures through automated work that avoids accidents and economic losses. The practice was carried out in two groups of workers, group A was trained with traditional apprenticeships, and group B used VR. At the end of the simulation, a questionnaire of 20 questions was applied to all participating workers. Group A obtained a percentage of correct answers of 87%, and in group B, 97% of the answers were positive. When applying the questionnaire after one month of training, the correct answers of group A decreased to 68 %, while group B obtained 87% effectiveness.

Shen (Shen et al., 2019), research similarly exposes a comparison between conventional training and VR. He described that the technology applied in the industry is a factor that saves costs. The study focused on a two-hand gearbox assembly task. The four participants in the simulation indicated that the use of VR generates learning in less time, requires less effort when it comes to learning about new topics and obtaining better performance in practice according to what was taught in the experiment.

Implementing a VR system on practices for welding is aimed at beginners who want to learn about the subject. This is how Chibani (Chibani et al., 2020), explains the main processes that the SPIDAR-WELDER system has to help the student manipulate the welding tools and generate essential techniques for the participants. At the end of the study, VR's main advantages were to avoid possible accidents in beginners, generate didactic learning on how to operate the machines, and carry out several pieces of training that ensure a critical and optimal performance in workers.

The main objective of Lustosa (Lustosa et al., 2018), is to implement the fourth industrial revolution in corporations. The system was based on a graphical mechanism and forklift control interfaces, using a joystick. The effect caused by the simulator in the eleven workers with an age range between 22 and 26 years was positive since, after undergoing a quantitative test, most of them answered that the training is easy to understand and execute. The test was carried out with a score of 1000 possible points, to which the users obtained a result of 827 in module 1 and 850 in module 2.

Randeniya (Randeniya et al., 2019), divided 6 participants, 3 through traditional training and 3 with VR.

The users who experimented with regular learning did so through PowerPoint, Slides, Videos, among others. The cognitive and psychomotor skills of the participants were evaluated, as well as the main results of time, intuition, completion of work and precision. The 3 participants with VR training scored 9.09, and the three users with conventional training averaged 6.31, which shows that VR is better than traditional training.

Nurkertamanda (Nurkertamanda et al., 2019), develops the issue of complications and errors that can occur in lathe motors. The objective of the work is to find a solution to the failures through a VR system made in Unity 3D and Blender. The system consists of two essential menus; i) an introduction where the parts and the functions of the lathe are shown, and ii) A menu divided into five user training options. Overall, users answered 336 questions, 24 each. Three hundred thirty questions were fully agreed. The system is efficient since it shows that users obtain better performance and knowledge thanks to this type of learning.

3. Case of study

In the industrial rhythm in which we find ourselves today, highly qualified operators are the ones who make the difference when measuring the productivity of a process or production line. For this reason, Industry 4.0 has become vitally important, providing new and efficient methodologies for human resources training.

Among these tools is VR, which is defined as the simulation of reality utilizing a computer. VR's advantages are focused on optimizing resources such as time or money and preventing workers from seeing their physical integrity exposed unnecessarily.

This study compares two forms of training in terms of fault detection and correction in three-phase electric motors. The first is based on the teaching adopted as usual within the health crisis that we are daring: videos, slides, and virtual classrooms through video calling software. The second uses an immersive VR application, within which interactive content and sensors are used that generate a sense of complete immersion for the user. See figure 1.

Because there is a wide range of possibilities in terms of failures within this type of motors, those that have been taken into account for this study, as they are the most common and because of their easy detection, are described below:

- **Broken Bars:** It causes a decrease in the regular performance of the induction motor. The failure begins with the fracture of a bar, and if it is not solved in time, it triggers the breakage of more rotor bars. Therefore it is necessary to give continuous maintenance to these machines (Maloma et al., 2017).
- **Inter-turn short citcuits:** are caused by damage to the coating that insulates the coil windings. This can affect the entire coil and even adjacent coils. Mechanical stress, high current peaks, or thermal impacts are some of the causes of the insulation. When this failure occurs, the machine has vibration problems, causing a major breakdown in its magnetic field. (Fireteanu et al., 2018).

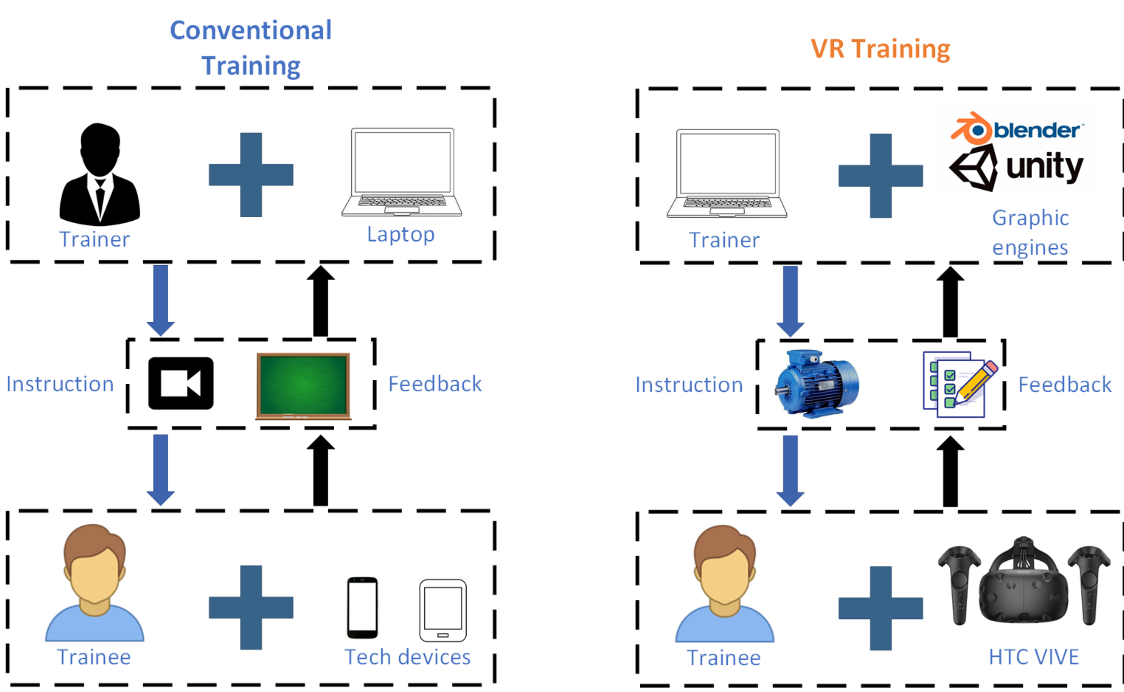

Figure 1. Conventional and VR training

4. Interactive system design

The graphical environment limits the virtual space where the user will develop and learn to identify the possible damages of an electric motor. Here, the Unity 3D graphics engine and Blender design software was used. Besides, the interaction of the interfaces with the HMD and HTC VIVE controls was achieved.

In figure 2, it is observed that the VR system is made up of three modules, i) Overview, which allows acquiring technical notions about three-phase induction motors. This has been implemented through a video. ii) Motor faults, where the user will be able to learn how to recognize an error due to broken bars or short circuits and how to repair each one of them. iii) Test, necessary to evaluate the knowledge acquired by the apprentices.

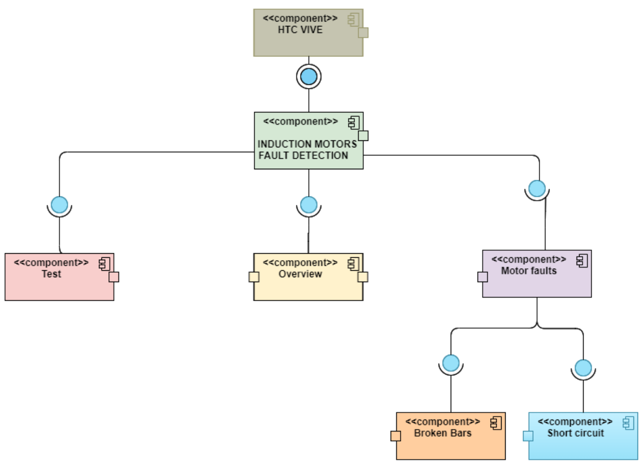

Figure 2. System component diagram

When starting the system, the user will find himself immersed in a mechanical workshop in order that his sense of presence is complete and feels within an environment that facilitates industrial learning. Here, a menu of options will be displayed where he will be able to choose between starting the training or exiting the system. See figure 3. If the user agrees to start the training, a video will be displayed explaining the basic principles of an induction motor, its parts and its applications. When finishing watching the video, a button will be enabled to continue to the next scene. This can be appreciated in the figure 4.

In figure 5, the running motor's nominal data and the signal of a phase in the oscilloscope are shown. It also states that the first error the user will have to deal with is broken bars. The characteristic sound of this error has also been simulated to familiarize the user with their surroundings and with the engine. In this interface, a button will take the apprentice to see, on a board, the difference in signal in each phase of a motor without fault and one with fault.

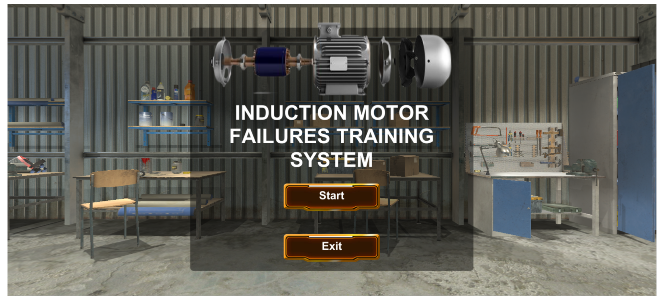

Figure 3. Options menu

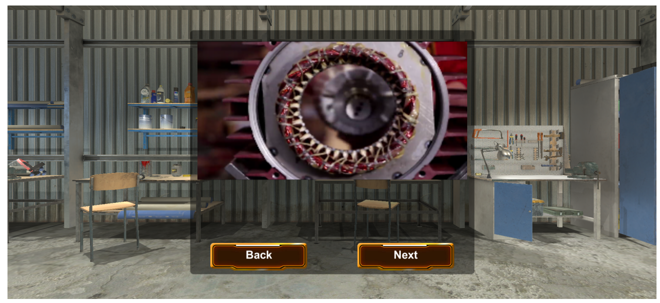

Figure 4. Tutorial

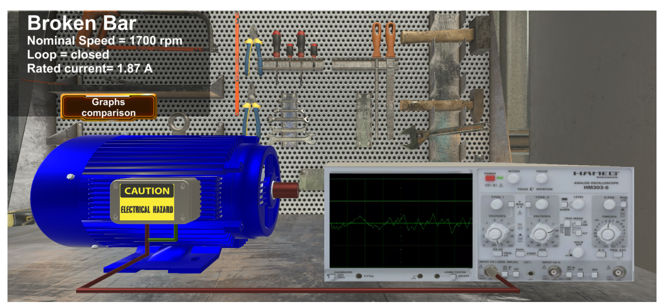

Figure 5. Broken Bars fault

In this scene, there is auditory feedback, 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 -10dbV. See figure 6.

Once the user has captured this information, the disassembled motor will be displayed, i.e. without its casing and stator. A red swinging arrow will identify physical damage to be visible and draw the trainee's attention. The above described can be seen in figure 7. After this, the user will be trained on how to solve

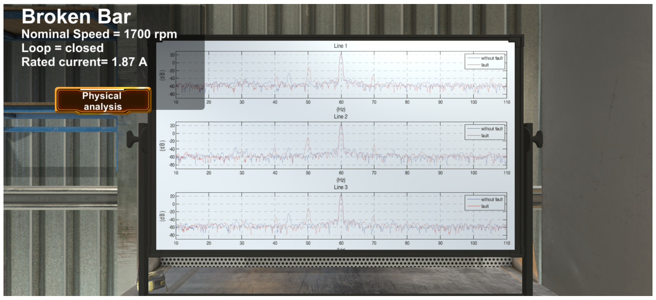

Figure 6. Broken Bars: graphs comparison

it. Here, the chosen method is brazing since it is the most common way to solve small rotor bars' small failures.When the repair process is finished, the damage disappears, faithfully simulating the actual repair process, having the option to continue with the subsequent failure. See figure 8.

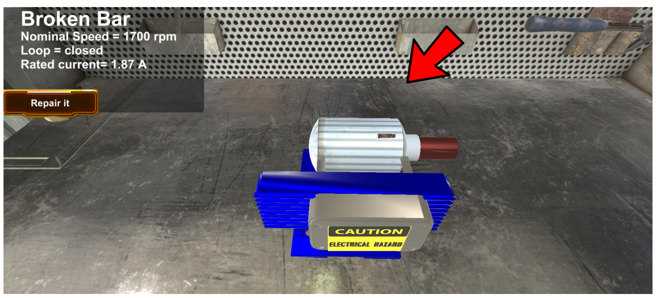

Figure 7. Broken Bars fault: Physical damage

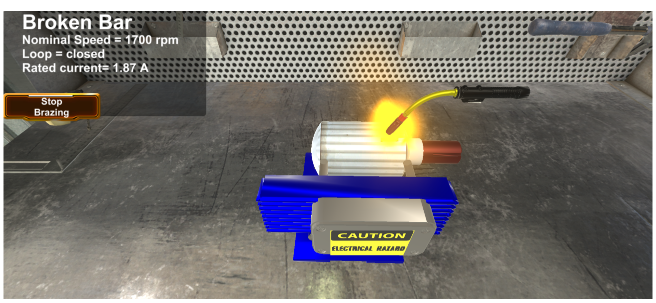

Figure 8. Broken Bars fault: Brazing process

The scenes developed for the inter-turn short circuits failure are similar. The nominal motor data displayed on the screen differs so that this fault's actual conditions can be created. Also, in figure 9 it can be seen that when the user goes on to compare the graphs, he will be able to learn that, in phase 3, there is a relatively small increase of 0.53 dBv in the frequency of 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 around 180 Hz, the signal spectrum increases 23 dBv above the noise level (Caiza et al., 2021).

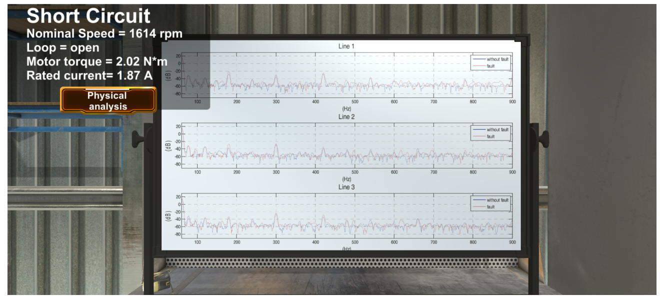

Figure 9. Short circuit: graphs comparison

Finally, to evaluate the knowledge acquired by each user, a questionnaire of ten multiple-choice questions has been implemented. Four have been directed to understanding the broken bars fault, four to the inter-turn short circuit and two to the general understanding of three-phase electric motors. Each question has three options, of which only one corresponds to the appropriate result. See figure 10. To guarantee the answers' reliability, each time the user selects an answer, it will be stored, and there will be no way to modify it. After this, he will automatically be immersed in the next question. In figure 11, it can be understood that when this evaluation has finished, a screen with the appropriate feedback will be displayed, i.e., username, score obtained, and the time spent.

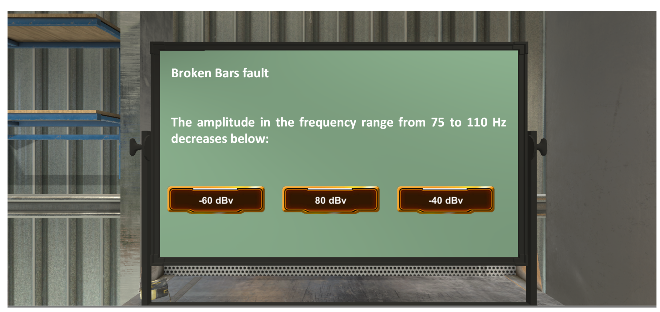

Figure 10. Test

5. System Usability Scale

It is a procedure that helps to measure the usability of technological systems. It was developed in 1986 by John Brooke and was based on ten statements where users respond through a satisfaction scale about each virtual operator's functionality. It is a test that allows users to determine virtual platforms purpose and level of service (Lewis and Sauro, 2009).

A rating from 0 to 100 determines how efficient the developed systems are. Those that obtain qualifica-

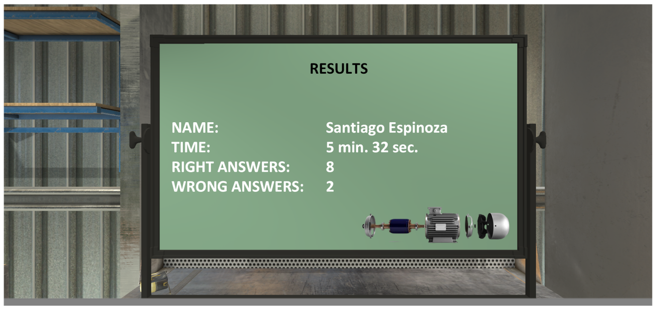

Figure 11. Test feedback

tions greater than 80 are excellent products, which do not have much to correct, and their qualification is A. Systems that are in a range between 70 and 80 are considered acceptable and have the designation B. Systems that are in the range of 50 and 70 are considered poor and have a C rating. Lastly, products that obtain a score below 50 are considered to have very little functionality and are valued with a D rating. The general guideline is shown on table 1 (Meldrum et al., 2012).

Table 1. SUS scores description.

SUS Score	Grade	Adjective Rating
>80	A	Excellent
>70-80	B	Good
50-70	C	Poor
<50	D	Awful

The formula used is shown in 1, where X represents the answer to each question. Each of the even-numbered questions is scored by subtracting the user's score from 5, that is (5 - X). Instead, subtracting one from the user-generated score (X - 1) is performed for odd-numbered questions. To determine the final score, the numbers of the positive and negative questions are added and multiplied by 2.5, thus generating the final result of the usability of a VR system (Sharfina and Santoso, 2017).

$$S = 2.5 * [\sum_{i=1}^{5}(X_{2i-1} - 1 + 5 - X_{2i})] \quad (1)$$

6. Experimental setting

To fulfil this research's objective, an experiment was designed with the participation of students and professionals from the city of Ambato-Ecuador with basic knowledge about electronics and automation. 30 people were chosen to take part in this experiment, and they were separated into two groups of 15 (a control group and an experimental group). 2 questions were included in this research:

- Q1: Does the use of digital systems like VR allow the optimization of training times?
- Q2: Is the VR system usable for induction motor fault detection and correction training?

As in other studies, the evaluation of acceptance was carried out through a survey following the guidelines presented by SUS (Kim et al., 2017; Naranjo et al., 2019) . Although there are other methods for measuring usability, SUS has been widely used in the evaluation of digital systems and VR systems (Lewis and Sauro, 2009).

The questionnaire's responses were established following the Likert scale: 1-Strongly disagree, 2-Disagree, 3-Neutral, 4-Agree, 5-Strongly agree. 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.

7. Results

7.1. Test

The conventional training process's main results indicate that in question 1, 33.33 % correct answers and 66.67 % wrong answers were obtained by the participants. In question 2, 53.33 % of the people answered correctly and 46.67 % wrong. Question 3 was successful at 53.33 % while 46.67 % failed. The participants in question 4 reached a higher number of correct answers, having only 33.33 % wrong answers. In question 5, 80 % correct answers were obtained. The result of question 6 was 73.33 % correct answers and the remainder incorrect. The value of correct answers was 46.67 % in question 7. Success in questions 8 and 9 was 53.33 %. Finally, in question 10, 40 % of the people got it right, and 60 % failed.

Using VR methodology, more significant learning is obtained since it is reflected in the number of correct answers for each question. In question 1, 80 % favorable responses were obtained, and only 20 % unfavorable responses. Question 2 shows that 73.33 % of the participants answered correctly and only 26.67

% incorrect. Of the 15 people evaluated, 80 % were successful in answering questions 3, and 4, and 20 % failed. Question 5 had the highest number of hits, reaching 93.33 %. Question 6 was answered 86.67 % correctly. Questions 7 and 8 obtained a 73.33 % success in answering. Finally, 80 % of the participants got questions 9 and 10 correct.

Figure 12 shows that in conventional training, 50 % of the grades are concentrated in scores of 6 or higher. The upper limit is 7, and there is also an outlier with a score of 3. The VR-based methodology describes that 50 % of the scores. Qualifications are found with values of 8 or higher, and the rest are results equal to 7. Also, one participant obtained an extreme value with a result of 6 points.

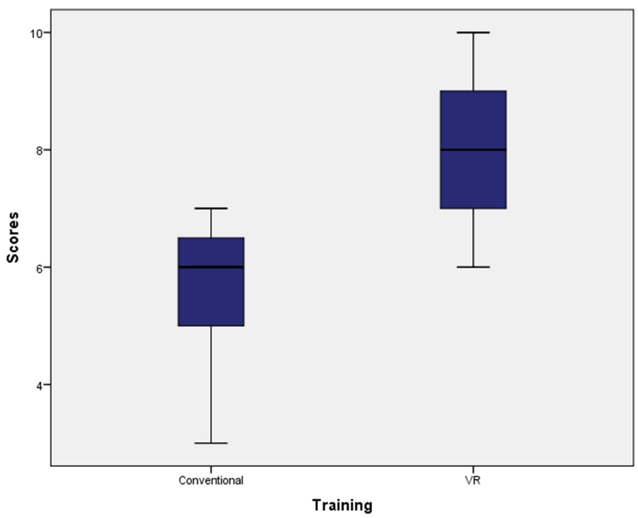

Figure 12. Conventional and VR scores

According to the average of the two groups' qualifications, it reflects a favorable result for the VR methodology, since 80 % of the participants clearly understood the different ways to repair an induction motor's errors. On the other hand, 55.33 % of the people trained with conventional methods generated essential knowledge for the maintenance of the mechanisms. All this can be seen in the figure 13.

To statistically verify the efficiency of VR training, the T-student tool has been used, and it has been based on two hypotheses: i) H_0 There is no significant difference between conventional training and VR training; y ii) H_1 There is significant difference between conventional training and VR training. The confidence level selected corresponds to α=5% = 0,05.

On the other hand, the Shapiro-Wilk test identifies the normality of the samples' observations smaller than 30 data. The significance values of conventional training and VR were 0.908 and 0.934, i.e., more significant than the p-value 0.05. These statistical data affirm

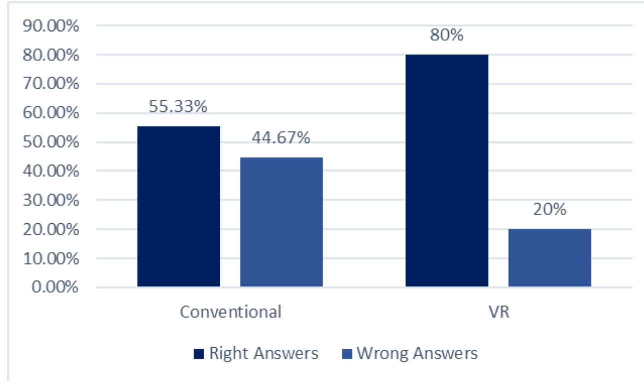

Figure 13. Scores percentage comparison

that the series are normally distributed. To determine the variances' equality, the Levene test is performed, where a significance value equal to 0.346 was obtained.

With the assumptions of normality and equality of the verified variances, the significance value (0.000003) was calculated. Being less than 0.05, this value allowed rejecting H0 and accepting H1, concluding that VR training is more effective than conventional training, providing solid knowledge, information retention, and correct understanding of the processes shown.

7.2. Training time

To determine the time resource's optimization, each of the two induction motor maintenance training was timed. The conventional instruction was carried out with the control group, which was trained in a constant time of 60 minutes. During this time, the professional's presentation, the content of the module studied, and the evaluation were considered. In contrast, VR training was carried out at varying times since each of the 15 participants in the experimental group needed different times to develop what they had learned. The experiment consisted of learning through the HMD and HTC controls. The total experience averaged 25 minutes 36 seconds.

In figure 14 It can be seen that there are significant time savings thanks to learning with VR, thus answering the first question posed 6. Besides, to complement the information, it was found that time is optimized 57.73 % concerning conventional training. This analysis states that there are better understanding and less training time with learning through Industry 4.0. In conclusion, we find that induction motor maintenance operators can gain more experience and learn through this technology. On the other hand, the optimization of resources in industrial entrepreneurs is essential since the costs are lower and can be the reason for the creation of new training methodologies

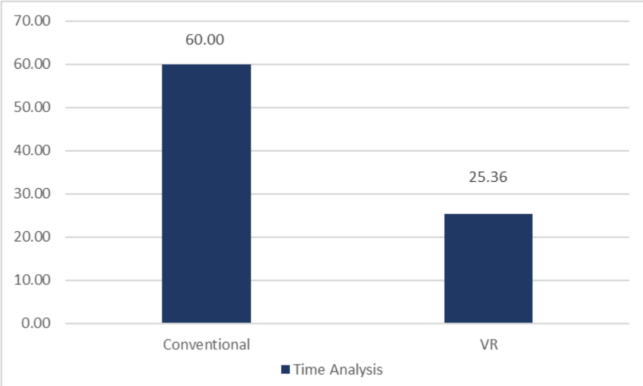

Figure 14. VR vs conventional training time

7.3. Usability

One of the primary purposes of the study was to verify the use that VR training can generate. This section indicates the result of the second question written in 6. For this reason, SUS was concerned to determine how acceptable to the public is the solution of errors in induction motors by VR. The experimental group responded using a Likert scale to the ten statements made by the procedure. The average obtained was 73.33 out of 100 possible. According to the methodology, it is concluded that it is a program that is friendly, easy to use, and intuitive since it is within the range of 70 and 80 points.

In figure 15, the participants' qualification is indicated after being subjected to the methodology proposed by John Brooke. After performing the arithmetic operations, it was obtained that the participants find an appropriate use in the system in all areas concerning an efficient VR system. According to the SUS procedure, training to solve induction motors' errors is acceptable for 12 people since it is in the range of 70 to 80 points. On the other hand, three people obtained grades between 65 and 70, so they find the application with minor usability.

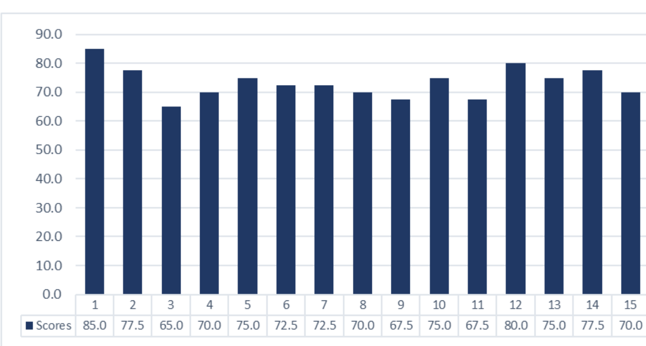

Figure 15. SUS scores

8. Conclusions and future work

A VR system has been developed for training in three-phase induction motor failure detection. The SUS methodology showed that users consider the system usable. However, being a first version of the model, there are still factors that must be worked on, such as the system's interaction, feedback, and robustness. On the other hand, it has been proven that this digital tool improves the understanding of industrial processes without the need to incur considerable costs or waste of time.

As future work, it is proposed to increase the number of scenarios to give the user the possibility of knowing more faults within this type of engine. It is also recommended to use agile methodologies to reduce development time. The expansion of this system through augmented reality and augmented virtuality is in the pipeline. Finally, it is proposed to carry out a study of the HTC sensors used to know the feedback efficiency.

9. Acknowledgements

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