Training virtual reality-based system for detection and simulation of motors failures

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Abstract. The need to have human resources trained efficiently is imperative. However, most industries do not give it the necessary importance. Similarly, staying technologically up-to-date allows the industrial sector to optimize its resources and satisfy the needs of its customers. This research presents the development of a virtual reality (VR) system for learning fault detection and correction in induction motors. It has been compared to a conventional methodology in terms of time and acquired knowledge. A 58% reduction was observed in the first parameter, while for the second, a p-value of 0.0000005 was obtained, thus demonstrating that this system is more efficient than conventional training in terms of learning. Finally, its usability was evaluated with the VRUSE method, with averages above 3.8 and standard deviations below 0.70.

1. Introduction
With the health crisis that the world is experiencing today, industries realized that having highly trained human resources is essential for their survival. However, some companies had to close their operations because they did not have an efficient training plan and because they were not flexible towards technological change.

With this background, the companies that managed to "survive" the COVID-19 pandemic were forced, together with their collaborators and employees, to digitize their processes, looking for new ways to reach the customer quickly and safely. However, they had to decide, continue operating while trying to adapt to the new normal, or stop their activities, taking a reasonable time to generate the necessary skills in all staff. Most companies chose the second option, thinking that implementing changes in live production could affect the quality, efficiency, and goodwill of their company [1, 2].

To solve this problem, they had to evolve towards Industry 4.0, which offers a variety of digital tools to improve the productivity of the production line and refine the skills and technical experiences of human resources. Among the technologies that help meet this objective, we can mention the Internet of things (IoT), cobots, VR, augmented reality (AR), 3D printing, artificial intelligence (AI), among others [3].

VR is commonly conceptualized as the digitization of environments that belong to the real world, whose goal is to transfer the user, through external elements such as Head-mounted displays (HMD's) and sensors, to immersive interfaces. However, it is necessary to consider that there are two types of VR besides immersive systems. i) Non-immersive VR reference, which is transmitted through monitors with 3D or 2D graphics without external elements. ii) Semi-immersive VR combines virtual scenarios with
This type of VR occupies devices such as projectors and high-performance computerized systems [4, 5].

This digital tool has a wide range of possibilities in terms of its use, being applied from video games through medicine and becoming a low-cost option within the industry. Among the most used software for VR development, there are two powerful graphics engines, Unity 3D and Unreal. Similarly, when it comes to immersive VR, the HMD's with the most use are those developed by Oculus and HTC [6].

As described in previous paragraphs, this article presents the creation of a VR system for training in the three-phase motor industry. What is intended is to detect and correct mechanical failures. Besides, its comparison with a conventional training system is presented. 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 six sections, including the introduction. In 2, the objectives of the study are delimitated. In Section 3, the development and usefulness of the interfaces are described, while in Section 4, the methodology applied for the usability evaluation, the selected sample, and the usability questions are shown. In Section 5, the results achieved are described; and, in Section 6, the conclusions and possibilities for future research are exposed.

![Figure 1. Conventional and VR training.](image)

2. Study case

Induction motors are alternating current mechanisms composed of a casing, a stator, and, commonly, a squirrel cage rotor. Now in the 21st century, these motors are implemented in most industrial processes [7]. Induction motors are used today because they are considered a machine that optimizes resources in industries. Despite this, they have common failures that can cause losses if they are not solved in time and are described below.

- **Rotor bar breakage**: Generates 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 [8].
- **Eccentricity**: It is an error that can occur in an induction motor, this can be static, dynamic or mixed. It is generated by a displacement of the rotor or stator shafts [9].
- **Short circuits**: They are created by minimizing the energy of the electrical resistance of the motor. When this failure occurs, the machine has vibration problems, causing a major breakdown in the magnetic field of the motor mechanism. By solving these problems, possible future deterioration can be avoided [10].
- **Damaged bearings**: It is a common but difficult-to-detect fault in induction motors. Damage to these instruments causes vibrations that wear down the motor at an accelerated rate, causing loss of inputs for the industries. The bearings are significant parts since they are the
ones that support the rotor. Detecting this error is extremely important since it allows maintenance personnel to solve the problem simply with the purchase of new bearings [11, 12].

Due to this, the objective of this study is based on comparing two forms of training for the detection and subsequent correction of faults in three-phase electric motors. Because of their ease of representation and their frequency of damage, the faults that have been chosen are i) Broken Bars and ii) Short circuits.

The first methodology to be developed is the teaching to which most of the academic world has become accustomed in the last year, i.e., using a video calling platform through which the instructor presents the content to his trainees either with videos or slides. On the other hand, the second methodology is an immersive VR system, which through the HTC Vive HMD and its sensors, recreates an engine repair shop. See Figure 1.

3. Virtual environment

The developed scenes limit the users' interaction environment, allowing them to identify the most common damages within three-phase motors graphically. For this purpose, the Unity 3D graphics engine has been used for the animation and final presentation of elements. On the other hand, Blender has been used for the design and rendering of 3D objects. Besides, to provide a full immersion feel, this system has been linked with the HMD, joysticks, and HTC sensors.

The VR system comprises three modules, i) Overview, which provides technical knowledge on induction motors. ii) Motor faults, where the two errors mentioned earlier have been implemented; and iii) Test to evaluate the capacity of the VR system to teach.

In Figure 2(a), it can be seen that the user, when starting the system, will find himself immersed in a repair shop for electrical and electronic devices, thus facilitating his familiarization with the industry. Two options will be visible. One of them will allow starting the training, while the other will allow exiting the system. When the apprentice chooses to start, a video will be displayed automatically, which will explain the applications of an induction motor, its connection, its operation, and its elements. See Figure 2(b).

In Figure 2(c), it can be seen that the first error that the user will have to familiarize himself with is that of broken bars. The connection of the first phase of the motor, which is in operation, has been simulated with an oscilloscope. Furthermore, an environment conducive to this error has been developed, i.e., nominal motor data such as speed, cycle type, and current have been entered. When the user verifies the shape of the signal presented on the screen, he can go to a blackboard, which will show the normal signal of each phase compared to an abnormal signal.

Here, it will be explained by audio that the amplitude in the frequency range 75 to 110 Hz decreases to lower values of -40 dBV compared to a normal 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 2(d) [13].

After this, the engine will be automatically demoted so that the physical damage can be identified. A red arrow will indicate this damage. At this point, the apprentice will understand how this physical fault occurs, in addition to being directed to another screen where the most common form of repair will be shown. See Figure 2(e).

The scenes developed for the failure of inter-turn short circuits follow the same logic, that is, the engine operation data is shown, the comparison of graphs between a normal signal and a faulty one, as well as the most common form of repair within this type of failure, are also deployed. In Figure 2(f) it can be perceived 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 over 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 [13].

Finally, to verify whether the system provides adequate knowledge feedback, it has been necessary to implement a multiple-choice questionnaire (three options) consisting of ten questions. Eight questions
have been directed to training in the detection and solution of broken bars and short circuits, while two questions were focused on the general knowledge of induction motors. When each question is answered, the selection cannot be modified. In Figure 2(g), it can be comprehended that when the user finishes with this evaluation, a screen will be displayed with the summary of the score obtained.

Figure 2. VR interfaces.

4. Experiment
To meet the objectives of this research, students and professionals from the city of Ambato- Ecuador who have basic notions about the operation of electric motors and automation were requested. Thirty people were chosen to be part of this study. Two groups were established, one control and the other experimental. Fifteen participants made up each group.

The acceptance evaluation was carried out with the VRUSE method. This tool helps developers to find possible slip-ups on virtual simulators for future system improvements. The diagnosis is made
through a questionnaire assessed using a Likert scale: (1) strongly disagree - (5) strongly agree. The rating depends on ten factors that, together with their description, are shown in Table 1 [14]. The following items, based on the VRUSE factors, were added to the survey:

(i) Does the VR system allow users to perform tasks completely?
(ii) Does the VR system allow users to communicate with the programmed interfaces naturally?
(iii) Does the VR system give efficient feedback during tasks?
(iv) Do the VR system grant guidance and assistance to perform tasks?
(v) Does the VR system respond the way it is expected?
(vi) Is the VR system intuitive and simple for education?
(vii) Does the proposed VR system drive the user over the programmed scenes?
(viii) Does the VR system allow users to amend wrongdoings?
(ix) Does the VR system let users feel completely immersed in the virtual environment?
(x) Is the VR system intuitive and clear to utilize?

Table 1. VRUSE factors.

| Factors                        | Description                                                                 |
|--------------------------------|-----------------------------------------------------------------------------|
| Functionality                  | The VR System should allow the user to perform complete tasks.              |
| User input                     | The VR System should allow the user to interact with it in a natural way.   |
| System output                  | The VR System should provide clear and understandable feedback.             |
| User guidance                  | The VR System should provide help and guidance to the user.                 |
| Consistency                    | The VR System should be consistent with user.                               |
| Flexibility                    | The VR system should allow the user to control it in a flexible way.        |
| Simulation fidelity            | The VR System should follow a model that drives the user over the virtual environment. |
| Error correction/ handling and robustness | The VR System should allow the user to correct errors.                        |
| Sense of immersion/Presence    | The VR system should allow user to fell part of it.                        |
| Overall system usability       | The VR system should be easy to use and intuitive.                          |

5. Results and discussion

5.1. Test

Once training was completed in both groups, they were evaluated. It is necessary to mention that both methodologies presented the same contents and the same test. The evaluation of the control group was done through Google Forms. The summary of the results of both groups can be seen in Figure 3. 50% of the grades for conventional training are concentrated between 5 and 7 with an average of 5.87. On the other hand, 50% of the grades for VR training were concentrated between 8 and 9 with an average of 8.27. Here it can be discerned that this latest training methodology is 24% more efficient, providing better teaching and allowing the acquisition of technical and useful knowledge for the electric motor industry.

In order to statistically verify the efficiency of VR training, the T-student tool has been used, and two hypotheses have been employed: i) HA There is no significant difference between the average of conventional training and VR; ii) HB There is a significant difference between the average of conventional training and VR. The selected confidence level corresponds to alpha = 5 % = 0.05.
The Shapiro-Wilk test has been used to identify the normality of a data set in small samples. The significance values, being greater than 0.05, both for conventional training and for VR, 0.100 and 0.063 respectively, show that the data are indeed normally distributed. Next, Levene's test was performed, obtaining a significance value equal to 0.252, thus assuming equal variances.

Finally, with the assumptions of normality and equality of variances, the significance value was calculated, obtaining a result of 0.0000005. Being less than 0.05, this value allowed accepting HB, concluding that training with digital tools typical of industry 4.0 is more efficient than conventional training.

![Figure 3](image)

**Figure 3.** Conventional (C) and VR training.

5.2. *Training time*

To establish the time difference between each methodology, each of them was timed. Because the control group was trained using the conventional methodology, a constant time of 60 minutes was obtained, in this time interval, the instructor's presentation, the content taught, and the evaluation was considered. In contrast, VR training was carried out at varying times since each of the trainees needed different times to complete the training. The experience, in this case, averaged a time of 24 minutes 56 seconds. In this instance, it can be discerned that digital tools such as VR optimize the time when training human resources by up to 58%. See Figure 4.

![Figure 4](image)

**Figure 4.** Average time.

With this analysis, companies by implementing digital tools for the improvement of their processes as well as for the acquisition of new skills by human resources, save maintenance costs, productive time of trained workers, and prevent the human resource is unnecessarily exposed to environments that may be hostile or harmful to its integrity.
5.3. Usability

The analysis in this section will be based on correlations, averages, and standard deviations. However, when talking about the first parameter, it can be observed that in several related works, there is a significant correlation between the VRUSE factors with significance values lower than 0.05 and correlation coefficients close to 1. In Table 2 the average values and standard deviations obtained are shown. The first ones are greater than 3.8, while the second data is less than 0.71. In this way, it can be said that the participants who were part of the experiment consider that the VR system for the detection and correction of failures in induction motors is usable.

| Factors | Media | Standard deviation |
|---------|-------|--------------------|
| 1       | 4.40  | 0.50               |
| 2       | 4.00  | 0.60               |
| 3       | 4.13  | 0.53               |
| 4       | 3.80  | 0.67               |
| 5       | 4.13  | 0.44               |
| 6       | 4.20  | 0.67               |
| 7       | 3.93  | 0.60               |
| 8       | 4.87  | 0.71               |
| 9       | 4.40  | 0.53               |
| 10      | 4.33  | 0.71               |

6. Conclusions and Ongoing work

A virtual reality system has been developed for training in three-phase induction motor failure detection. The evaluation of both time and knowledge showed that these systems have several advantages over traditional teaching methods. However, it is necessary to consider that the system needs to be polished, specifically in terms of guidance and help for the user, fidelity of the simulation, and sense of immersion. On the part of the industries, the decision to enter the fourth industrial revolution has been the correct one since it represents the optimization of valuable resources if appropriately handled.

As future work, it is proposed to work on the requirements of the users who were part of this first sample, that is, to improve the user experience. On the other hand, it is aimed to increase the number of failures proposed and the use of augmented reality. Finally, it is intended to validate this system with larger samples and more robust usability tools.

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