Uso didáctico de la realidad virtual inmersiva con interacción natural de usuario enfocada a la inspección de aerogeneradores

Didactic use of immersive virtual reality with NUI focused on the inspection of wind turbines

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RESUMEN

Los sistemas de realidad virtual inmersivos tienen una creciente relevancia en el ámbito educativo como herramientas didácticas que motivan el aprendizaje a través de dos conceptos clave: la inmersión y la interacción. En este documento describimos el uso de sistemas de realidad virtual en la educación y tomamos como caso de estudio un sistema de realidad virtual inmersivo 3D con interacción natural de usuario desarrollado con el propósito de facilitar la inspección de aerogeneradores con fines didácticos. El sistema sugerido busca la convergencia tecnológica de equipos de visualización, adquisición de información y software de gráficos. Para lograrlo, seguimos la metodología de desarrollo de software basado en componentes de Pressman. Los resultados cualitativos de una primera evaluación al sistema indican que la propuesta permite experimentar la realidad virtual inmersiva y ofrece una gran similitud al entorno real, con la posibilidad de interactuar por medio de gestos y movimientos corporales. Esto contribuye a motivar el aprendizaje y fomentar el interés de los usuarios en practicar con esta tecnología. Además, la convergencia tecnológica entre los equipos de visualización, interacción y software gráfico permite dar un paso adelante en el desarrollo de este tipo de herramientas didácticas.

Palabras clave
Realidad virtual inmersiva, tecnológica educativa, ambientes virtuales de aprendizaje, herramientas virtuales de aprendizaje

ABSTRACT

Nowadays immersive virtual reality systems have a growing relevance in educational environments as tools to encourage learning through two important keys concepts: immersion and interaction. This paper describes the use of virtual reality systems in education, taking as a case study an immersive 3D virtual reality system with NUI developed for the purpose of facilitating the inspection of wind turbines for didactic purposes. The proposed system searches technological convergence of visualization devices, data acquisition tools and graphics software. To achieve this system a software development methodology of Pressman was followed. The qualitative results of a first evaluation at the system indicate that the proposal allows an immersive virtual reality experience offering a great similarity to the real environment, with the ability to interact through gestures and body movements. This helps to motivate learning and stimulate interest in practicing with this technology by users. Moreover, achieved technological convergence between visualization devices, interaction tools and graphics software, allows us to make a step forward in the development of this type of teaching tools.

Keywords
Immersive virtual reality, educational technology, virtual learning environments, virtual educational tools

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INTRODUCTION

Currently, conventional teaching methods are being complemented more frequently with 3D virtual reality systems given their didactic potential (Gisbert & Esteve, 2013). This is due to the fact that virtual reality systems compared to traditional teaching, including other IT applications with a didactic proposal, offer the user a 3D visual environment which is highly interactive and very close to reality, all of this through two key components: immersion and interaction (Flores, Camarena & Ávalos, 2014). For Freina and Ott (2015), immersion, interaction and participation of the users in the narrative, as basic principles of virtual reality, offer a very high potential in education by making learning more motivating and attractive.

According to Springer (2008), immersion may be divided in several types with characteristics and objectives that must be met in order to be considered as an immersive system. Along these lines, an immersive virtual reality system strives that the user looses contact with the reality by perceiving in an exclusive manner the stimuli of the virtual world. However, achieving immersion in virtual reality systems is up to now restricted solely to special immersion, i.e., the perception of being physically present in a virtual world (Freina & Ott, 2015). Slater (2009) distinguishes two ways of experiencing immersive virtual reality: a HMD (head-mounted display) virtual reality headset and a three-dimensional type of cave environment.

The HMD headgear is placed exactly before the eyes to center the screen in such a way to avoid any distraction. The headgear contains an internal magnetic sensor that detects the user's head movements, as well as when the user turns his/her head, the graphs that appear reflect a changing point of view which allows a natural visual exploration of the environment (Springer, 2008). The CAVE environment is made up of four and six $3m^3$ walls that operate as stereo projection screens. The images are determined as a head follow-up function in such a way that the participants may move physically through a limited space, at least in regard to the visual system, and move their head arbitrarily in order to be able to perceive images. Generally, the audio system is integrated by a set of loudspeakers discretely positioned around the CAVE (Olguín, Rivera & Pozas, 2008).

Traditionally, the means of interaction for virtual reality systems have been conventional (keyboard, mouse and joystick). However, the current tendency is increasingly focused on incorporating more natural forms of interaction, such as touch, speech, gestures, handwriting and vision. These are known as the user's natural interfaces (Ballmer, 2011). The integration of the user's natural interfaces with the 3D virtual reality environments allows the user to interact with virtual objects in a very similar way as he/she would do with real objects (Kaushik & Jain, 2014). Hence, interaction through gestures is in the rise.

Immersion technology and interaction used in 3D virtual reality systems allow overcoming didactic obstacles present in topics that, given their nature, contain hazardous or potentially hazardous situations for the students (Flores et al, 2014). For example, one may have access to difficult or dangerous sites easily and safely without the need to go there physically. In the educational sector in particular, there are several subjects that require the students to visit working sites with the object of reinforcing learning. In the case of the wind-energy sector, knowing the installations, the infrastructure of a wind-energy farm as well as the elements that make up a wind turbine is of great relevance. Different circumstances make this task somewhat more complicated since, for safety reasons, the wind-energy farm must stop operating given the industry confidentiality restrictions; furthermore, it is impossible to access all the facilities. Generally, visiting a wind-energy farm means having to travel long distances from the educational centers, and this gives rise to traveling expenses.

Along these lines, making use of the 3D virtual reality for training students in human resources in the wind-energy sector represents a viable educational modality that allows showing elements that intervene in the energy generation process, besides students taking advantage of other inherent benefits of the virtual reality systems such as:

- Avoiding the risk of being electrocuted by being close or in a wind turbine (Hernández, 2016).
- Avoiding the risk of climbing an 80 to 150-meter wind turbine (Hernández, 2016).
- Avoiding the complex problem of locating wind-energy farms and, in some cases, farms difficult to be reached or are far from emergency services (Tesicnor, 2014).
- Avoiding infringing the industrial secret of wind-energy farms by using generic models. Moreover, there is the advantage of repeating virtual activities as often as required (Trujillo, 2016).

This article describes the didactic use of an immersive 3D virtual reality system combined with the natural interaction of the user. In order to achieve full visual immersion, a HDM virtual reality headgear as well as body gestures recognition were used for the natural interaction of the user. This focuses on the inspection of wind turbines with the didactic objective of reinforcing learning of the elements that intervene in the process of generating wind-energy. The application of this immersive virtual reality system will be a didactic support tool for the students in a Master's degree in Wind-energy Sciences at Universidad del Istmo, more specifically for the subjects Introduction to wind-energy turbine technology and Seminar on wind-energy turbine technology, since this application allows inspecting the exterior as well as the interior of a wind turbine and the elements that integrate it.

RELATED WORKS

Virtual reality systems have been used at a greater or lesser extent in several sectors such as entertainment, tourism, heavy industry (refineries, mines, etc.), renewable energies and education, among others. Papers referring to the educational and wind-energy sectors are of special interest in this article.

The study conducted by Gisbert and Esteve (2013) on the educational potential of the 3D virtual reality environments, such as Second Life or Open Simulator through two educational experiences focused on the student, in line with other publications, conclude that these environments have great potential in the educational field to conduct practical learning experiences as well as to carry out experimentation activities, tests simulations or teamwork activities.

As for Fominykh, Prasolava-Førland, Morozov, Smorkalov and Molka-Danielsen (2014), they go beyond the immersion and interaction levels provided by these environments. They are of the opinion that a 3D learning atmosphere provides a more efficient way to motivate learning than a traditional classroom does. These authors developed three prototypes to increase the levels of immersion and interaction of the users. They achieved so by means of a 3D immersion cave, a virtual reality headgear and, lastly, a user's position follow-up system (interaction through gestures). Gisbert and Esteve (2013) directed their study to the training of professors and digital competencies, while Fominykh *et al* (2014) focused their prototypes as a didactic resource that professors may use to interact virtually with the students.

Flores *et al* (2014) research on the use of virtual reality technology as an innovative didactic strategy reveals that in the last years, mainly in developed countries, virtual reality has positioned itself in educational environments as an alternative approach to traditional learning experiences. Freina and Ott (2015) study on the revision of literature on virtual reality in education during 2013 and 2014 also reports the same findings. The United States of America and the United Kingdom are the countries with the highest number of indexed publications.

Flores *et al* (2014) focus their research on the potential use of virtual reality particularly for the studies in Electrical Engineering at the Instituto Politécnico Nacional [National Polytechnic Institute], and identify subjects that, given their nature, require the understanding of abstract concepts, generate hazardous situations and require industrial visits or know equipment on the field. In this regard, the authors have determined that, even when didactic obstacles may occur in most of these subjects, it is however possible to apply virtual reality to counter them. Since this research is documental, the authors do not expound any virtual reality system that allows addressing such subjects.

As for Freina and Ott (2015), they point out that the main motivation for using immersive virtual reality in education and training is to offer the opportunity to experience situations in which physical access is difficult or impossible; for example, to immerse in a historic era or visit highly dangerous facilities, among others. For these authors, said virtual experiences begin being more feasible in the field of education and training given the entry into the market of the HMD Oculus Rift headgear at an affordable cost in comparison to the past. Hilfert and Köing (2016) consider the Oculus Rift headgear as a key element of "low-cost" immersive virtual reality systems for engineering and construction applications.

It is noteworthy that the systems referred to by Hilfert and Köing (2016) include user's natural interfaces through gestures that use devices such as Kinect and Leap Motion, among others. It is worth mentioning that Grabowski and Jankowski (2015) works, as cited by Hilfert and Köing (2016), who tested different configurations of HMD headgears and interaction means for the training of miners in the coal mining industry, discovered that test subjects preferred highly immersive virtual reality systems. Furthermore, they show that the detection of gestural commands is a better option than a wireless joystick since the result of training is sustained on a long-term basis.

In regard to the wind-energy sector, the use of virtual reality is somewhat recent and is not yet common. So far, in the search for papers related to the foregoing, ACCIONA Virtual Experience Mobile Application (ACCIONA, 2015) and Immersive Virtual Reality Experience (ACCIONA, 2016) are the only two cases to have been developed on the wind-energy industry and both were conducted by ACCIONA, the Spanish renewable energy company. ACCIONA (2015) presents a mobile application with a list of projects to visit through immersion. One of these projects is the Waubra wind-energy farm in Australia. The technology necessary to execute this application consists of a high-end smartphone and a compatible VR headgear to mount on the phone. Next, ACCIONA (2016) has shown an immersive virtual reality consisting of a HMD headgear and two wireless commands through which the users can tour the wind-energy farm virtually, enter the wind turbine, take an elevator to the gondola, inspect the interior, interact with the elements and go up to the upper part to see the scenery from the top of the turbine.

Moreover, two papers linked to research and development focusing on the wind-energy sector (CEMIE-Eólico, 2016), have been found in the educational sector. One of these papers (Trujillo, 2016) implements a virtual tour of the wind-energy farm to motivate and stimulate the students to carry out activities to visit the wind-energy farm facilities. To do so, this application uses a mouse and a 360 Xbox control as means of interaction and the HMD Oculus Rift headgear as a mean of immersion. The second paper (Hernández, 2016) develops a 3D platform and uses Kinect as a mean of interaction. This 3D platform is used as a didactic resource to acquire knowledge on the components and general operation of a wind-energy turbine.

Going over the technology that uses the virtual reality systems aforementioned allows us to identify that the tendency is to use HMD headgear as an essential immersion element (Fominykh *et al*., 2014; Freina & Ott, 2015; Hilfert & Köing, 2016, ACCIONA, 2016; Trujillo, 2016). Given its affordable cost, the use of the Oculus Rift device predominates (Freina & Ott, 2015; Hilfert & Köing, 2016). Kinect is the most widely used device in regard to interaction devices that recognize gestural commands (Fominykh *et al*., 2014; Hilfert & Köing, 2016; Hernández, 2016). Besides these two hardware devices, there is a third element, graphics engine software, which is also of great importance. The videogame sector provides several options of graphics engine for the development of videogames that have made immersive virtual reality possible; Unity 3D is one of the engines widely used given its compatibility with Oculus Rift headgear (Trujillo, 2016), and with the Kinect device (Hernández, 2016).

DESCRIPTION OF THE PROPOSED SYSTEM

Through the system proposed in this article, it is possible to identify the technological convergence referred to by Flores *et al*. (2014), which leads to immersive virtual reality systems. This convergence involves six technologies: display equipment, information acquisition equipment, software (graphics engine), processing hardware, additional accessories and communication systems. Figure 1 outlines the particular case of technological convergence that occurs in the immersive virtual reality system with natural interaction of the user proposed by the inspection of wind-energy turbines.

Figure 1. Technological Convergence for the particular case of the system proposed
Source: Adapted from Flores *et al*. (2014).

The methodology used to achieve the technological convergence of the three main components: acquisition, display and software, builds upon the stages of development based on components (Pressman, 2010), framed within the seven phases of the life cycle of system development (Kendall & Kendall, 2005). Figure 2 shows the relation among three of the phases of the life cycle of the system development and the five stages of the development based on components. It is worth mentioning that a similar technology was used in Zúñiga, Amador, Mejía, Morales and Mota (2014) for a three-dimensional virtual environment oriented to Teotihuacan tourism diffusion. However, they used the prototype method instead of the development based on components.

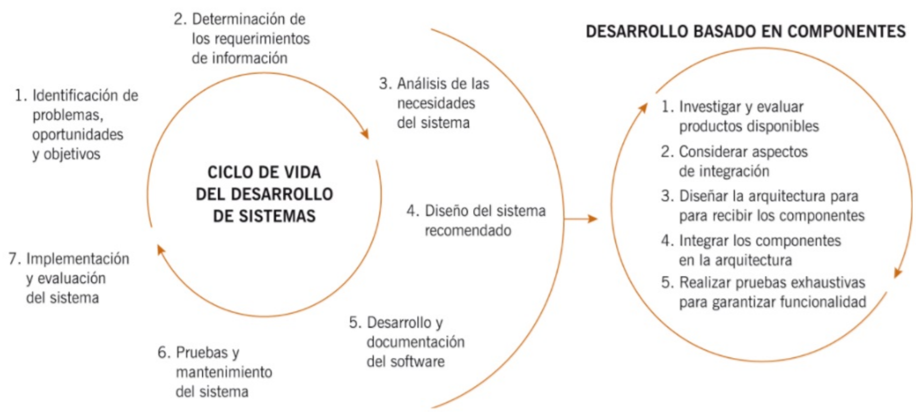


Figure 2. Life cycle of system development and development based on components
Source: Adapted from Kendall and Kendall (2014) and Pressman (2010).

During the first phase of the life cycle of system development, we identify field visits to wind-energy farms as a paramount necessity in order to reinforce learning during the training of human resources in the Master's degree in Wind-energy Sciences at Universidad del Istmo, more specifically for the subjects Introduction to wind-energy turbine technology and Seminar on wind-energy turbine technology. These present the type of didactic obstacles referred to by Flores *et al.* (2014), since they generate hazardous situations, require industrial visits as well as knowing the field equipment. In this regard, several authors coincide with the opinion that immersive virtual reality systems are a viable alternative that contributes to overcoming those didactic obstacles besides motivating learning in a safe environment for the student (Fominykh *et al.*, 2014; Flores *et al.*, 2014; Freina & Ott, 2015). Therefore, the objective of the system proposed is conceived as "developing an immersive virtual reality with natural interaction focused on the inspection of wind-energy turbines for educational purposes".

The second phase of the life cycle establishes the information requirements according to curricular coincidences of the two subjects identified in phase one, i.e., field visit to a wind-energy farm in order to know and measure the main components of a wind-energy turbine, such as the tower, generator, rotor, orientation systems, gondola, among others. In this sense, the system proposed must:

- Provide a 3D representation of the environment of a wind-energy (wind-energy farm) close to reality.
- Present an external 3D structure of a wind-energy turbine from its foundation to its gondola, with sufficient detail level to differentiate the external components clearly.
- Show a 3D display of the main internal components of the gondola and distinguish them one from the other perfectly.
- Offer the user relevant information of the internal as well as external components of the wind-energy turbine.
- Provide an efficient immersion mechanism to avoid visual distractors in order to enable the user to concentrate on the inspection from different perspectives of the 3D internal and external models of the wind-energy turbine.
- Have a user's natural interface through gestural commands to avoid the use of joysticks.
- Have an avatar to navigate the exterior, interior and surface of the gondola of the wind-energy turbine.
- Set the 3D environment acoustically with the sound of wind.

The intent of using these characteristics is twofold. The first is to generate a virtual learning experience as close as possible to reality without the risks implied by a live visit, and the second is to motivate the students to learn.

The third phase of the life cycle is addressed with the two first stages of the development based on components. The analysis of the requirements allows pinpointing the need of a system that contributes to experimenting immersive virtual reality together with a user's natural interface based on gestural commands. Said necessity requires investigating and assessing the products referred to in the papers related in regard to their cost (economic feasibility) and aspects of integration of the components.

In agreement with Freina and Ott (2015) and Hilfert and Köing (2016), the Oculus Rift headgear has been identified as the most viable option at a cost of $599 US. In regard to the user's natural interaction, the Kinect device is also one of the major potential and known devices to final users (Fominykh *et al.*, 2014; Hilfert & Köing, 2016; Hernández, 2016). This device cost $109.99 US. Both components have been tested previously in the Unity 3D videogame graphics engine (Trujillo, 2016; Hernández, 2016). This indicates that this is the ideal videogame engine to be integrated in a single system.

The computational capacity is another aspect to be considered in implementing and executing immersive virtual reality. By taking as reference the requirements of the three components selected, we consider using two computational equipments: one for the development and the other for the execution of the final system. For the development, we selected a Dell® Precision 7910 work station with a Xeon® CPU E5-2623 V3 @ 3.0 Ghz, 16 GB memory and a GPU NVIDIA® QUADRO® K2200 card at a cost of 57,146 pesos, and for the execution of the system, a Dell® Inspiron 15 computer with an Intel® CoreTM i7 processor, 8 GB memory and a GPU NVIDIA® GeForce® 4GB card at a cost of 22,999 pesos.

The fourth phase of the life cycle is addressed jointly with the third stage of development based on components since it is at this stage that the system logic is designed which allows integrating in a coordinated way the hardware and software technological components. Figure 3 shows, through a state machine, the logic design of the proposed system. Currently, there are three displays: first, at the level of the floor of the turbine, second, in the interior of the gondola and, third, on the gondola. At that stage, it was also necessary to define and detail all the 3D models to be presented in the immersive virtual reality system besides establishing the necessary gestural commands for interaction.

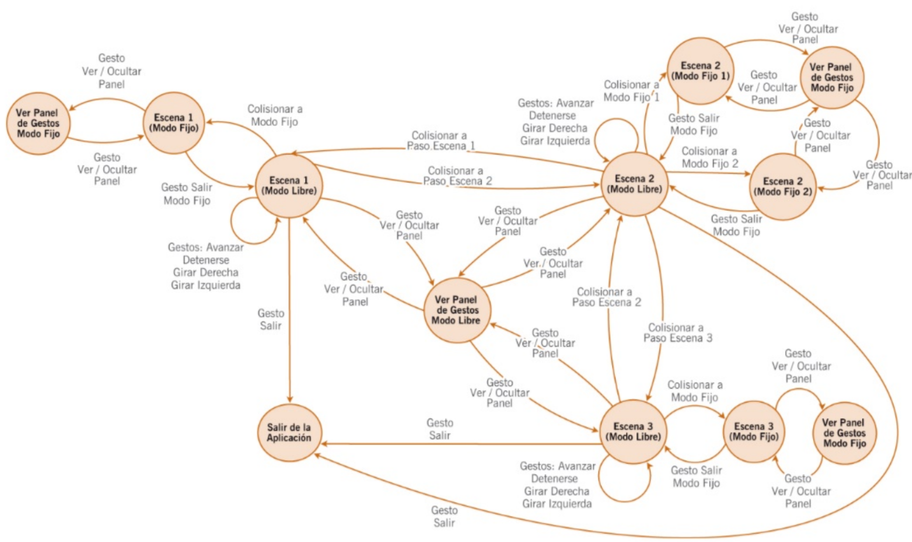


Figure 3. State machine describing the system logic
Source: Developed by the author.
Note: The fixed mode allows showing panels with information; the free mode facilitates navigating within the scenes.

The two last stages of development based on components took place during the fifth phase of the life cycle. The Kinect device was the first component to be integrated and tested exhaustively in 3D Unity to ensure its functionality. This allowed generating a first version of the completely operational system without the HMD headgear. Next, the Oculus Rift headgear was integrated which met the immersion and interaction requirements identified in the second phase of the life cycle.

During the sixth phase, preliminary tests were designed and conducted, and in which the people involved participated in the analysis, design and development. Furthermore, a couple of users participated in detecting and correcting problems in the interface and operation of said tests. The problems detected and corrected were as follows:

- The system had the tendency to confuse some of the gestures chosen initially besides not being as intuitive as expected. Therefore, we have chosen new gestural commands (See Figure 4) that were more intuitive and, in turn, were differentiated by the system with more precision.
- By showing a panel with relevant information on a component, the panel would obstruct most of the component. The solution consisted in using a glass type material for the panels that allows reading the description of the component and, at the same time, see the components to be inspected (See Figure 5).
- The readability of the text presented in the interface would diminish on the extreme right or left of the field of vision of the Oculus Rift headgear. This problem was solved by placing all the panels shown to the user at the center of the camera (focus point). After correcting the problems, the first final version of the system was developed to be implemented and evaluated in the seventh phase of the methodology.

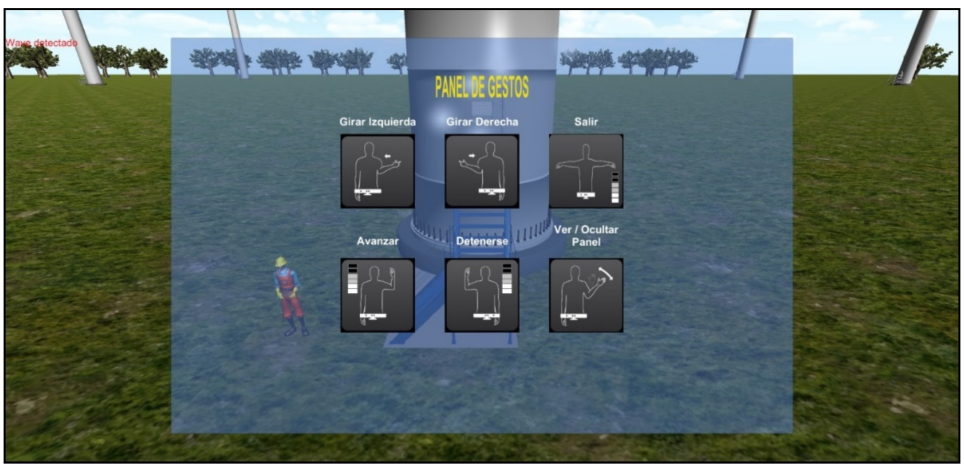


Figure 4. Gestural command panel to turn left, right, go forward, stop, see/block the panel
Source: Developed by the author.

Figure 5. Text panel with information on the component called multiplier
Source: Developed by the author.
Note: The user put a green circle over said component.

The seventh and last phase corresponds to the implementation and evaluation of the system. A 3.2 meter long by 2.9 meter wide and 2.8 meter high cubicle was set up with a 60 Hertz artificial light. The glass window and door were covered with white bond paper to avoid external interferences that could affect recognizing gestures. Different technological components of the system were installed within this space: computer equipment with installed software, Kinect device, HMD Oculus Rift headgear and an audio system (See Figure 6).

A sample of twenty students in the Master's degree in Wind-energy Sciences, five professors of Universidad del Istmo and five undergraduate students participated in the evaluation of the system. A ten question multiple choice survey was administered to the thirty participants with the purpose of identifying factors of assimilation of the use of technologies associated with immersive virtual environments.

The data collected for each user's profile are: age, sex, schooling, occupation, previous visits to wind-energy farms, experience with videogames, use of the Kinect device, use of HMD Oculus Rift headgear, use or tests of technology of virtual reality and height vertigo. The system test consisted in doing two tasks without using the Oculus Rift headgear (See Figure 6a), and afterwards, do the same two tasks plus four other similar ones using the headgear. The tasks consisted in exploring the exterior setting at floor level of the turbine, exploring the interior as well as the exterior of the gondola, passing from a free navigation mode to a fixed mode where it was possible to visualize the panels with information on the components of the wind-energy turbine.

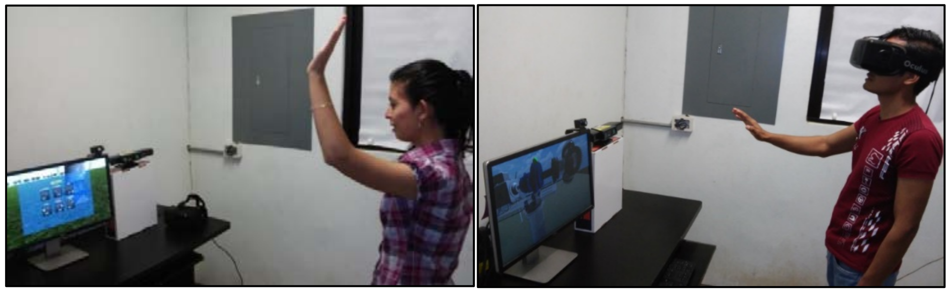


Figure 6. Space set up for implementation and evaluation: a) by using the Kinect device only, and b) by using the HMD Oculus Rift headgear and the Kinect device
Source: Developed by the author.

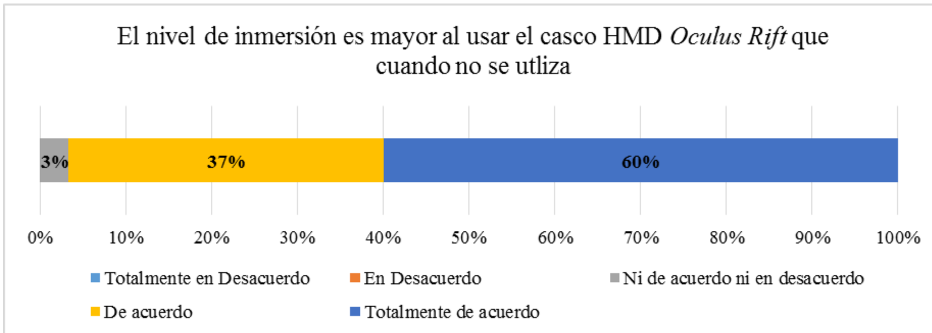
It should be pointed out that the tasks to be performed by the users were designed in such a way that the time of use of the headgear would not exceed twenty minutes, as suggested by Guerrero & Valero (2013) in their paper on the side effects after using the immersive virtual reality in a videogame. After the test, the users were given another survey designed with an eight five-level Likert type items; four questions were designed to evaluate the compliance with the requirements established in the second phase of the life cycle. The other four questions focused on measuring aspects such as the interest of the users to use the virtual reality technology to reinforce their knowledge, the didactic potential of the technology used in training practices and the assessment of the side effects perceived by the users. The results of the eight items and their discussion will be addressed in the following section.

RESULTS

The first survey allowed identifying the profile of the thirty test users. The age of the participants varied from twenty to forty years of age. The 20-27 years old range represented 73%; 20-30, 20%; and 30-40, 7%. 83% of the participants were male and 17% female; 60% of all the participants had very little experience in using videogames; 17% had no experience whatsoever and only 23% were regular gamers. This datum is important since the technology that uses the proposed system was generated from the videogame industry. In spite of the little experience of the users with videogames, 53% of them had used the Kinect device at least once, and 43% had used the HMD Oculus Rift headgear. However, 60% of the participants had not carried out tests or used some kind of immersive virtual reality system. Another valuable datum is that 60% of the users had at one time visited a wind-energy farm.

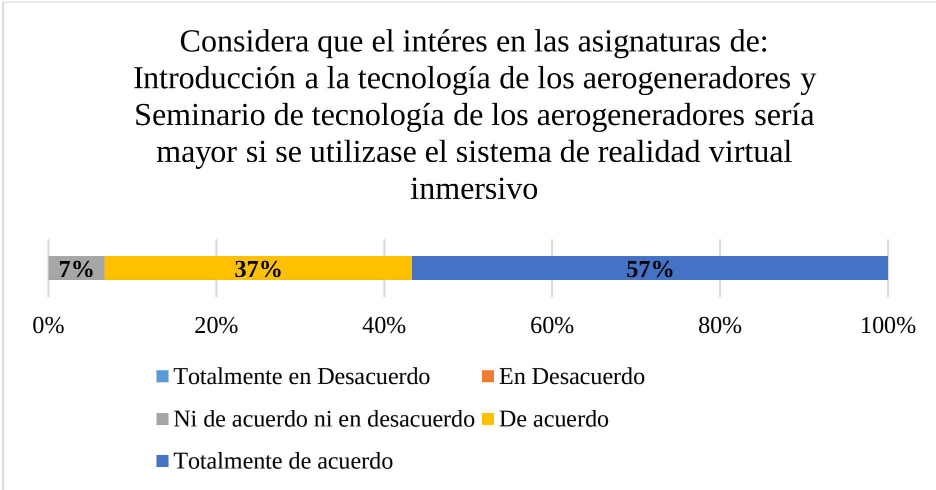
The survey that followed the test showed the following results:

- Of all the users, 60% totally agreed that the level of immersion was greater when using the HMD Oculus Rift headgear in comparison to not using it, while 37% agreed and only 3% did not agree or disagree (See Graph 1). The result shows that the requirement to have an efficient immersion mechanism was met. This also confirms the point made by Slater (2009), i.e., this type of headgears lets the users experience immersive virtual reality.



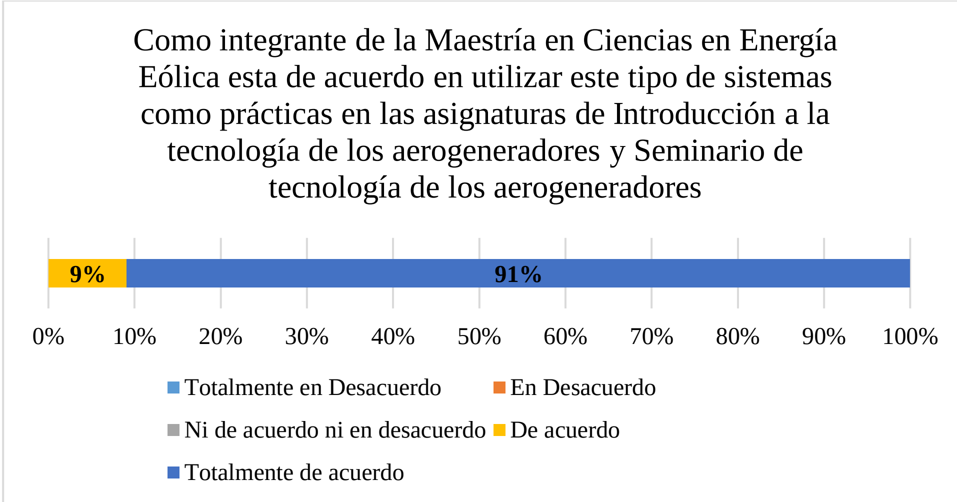
Graphic 1. Level of immersion perceived with the HMD Oculus Rift headgear
Source: Developed by the author.

- In spite of the fact that only 60% of the users have visited a wind-energy farm, 72% of all the participants agreed that the experience during the test with the HMD Oculus Rift headgear is greatly similar to the real inspection, while 17% totally agreed and 11% did not agree or disagree.
- Of all the users, 50% agreed that it is possible to differentiate the external components of the wind-energy turbine clearly, and 50% totally agreed. The result shows that the corresponding requirement was met. However, a later version of the system improved the level of details.
- Of all the users, 60% indicated their total agreement in being able to distinguish the internal components of the gondola of the wind-energy turbine perfectly; while 37% agreed and 3% did not agree or disagree. The result shows that the corresponding requirement has been met. However, a later version of the system improved the level of details and contrast between the internal components.
- Of all the users, 57% totally agreed that by using the immersive virtual reality system the interest in the subjects Introduction to wind-energy turbine technology and Seminar on wind-energy turbine technology was greater (See Graph 2), while 37% agreed and 7% did not agree or disagree. These results are consistent with the point raised by Fominykh et al. (2014), in the sense that a 3D learning environment provides a more efficient way of motivating learning than a traditional classroom.



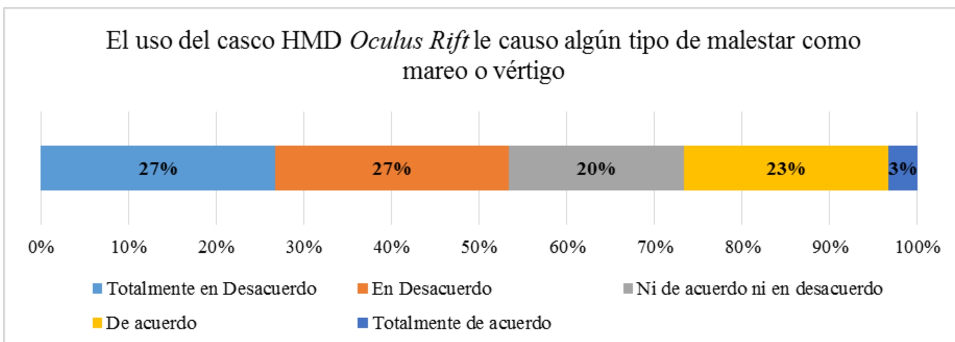
Graph 2. Interest in the subjects when using an immersive virtual reality system
Source: Developed by the author.

- Of all the users, 70% totally agreed that by using the immersive virtual reality system to inspect wind-energy turbines helped them strengthen their knowledge of the subjects Introduction to wind-energy turbine technology and Seminar on wind-energy turbine technology, while 27% agreed, only 3% did not agree or disagree. If we calculate only the users enrolled in the Master's degree in Wind-energy Sciences (20 over 32 enrolled), as well as two of the professors that give the subjects referred to, the percentage of those who totally agreed changes to 68, and those who agreed to 27, while those who did not disagree or agree were 5%. These results confirm that the didactic purpose of the proposed system is totally reachable.
- When considering the users who are students or professors of the master's degree in Wind-energy Sciences (20 students and two professors), 91% totally agree in using this type of systems to carry out practices in the corresponding subjects, while 9% agree (See Graph 3). These results confirm partially the conclusions of Gisbert and Esteve (2013) study, more specifically in carrying out practice training experiences.



Graphic 3. Interest in carrying out practices using immersive virtual reality systems
Source: Developed by the author.

- Of all the users, 3% totally agreed that the use of the HMD Oculus Rift headgear caused them some discomfort, dizziness or vertigo; while another 23% agreed (See Graph 4). These results confirm what Guerrero and Valero (2013) pointed out, i.e., the visual perception of the immersion can be so real that the user needs to use the HMD headgear gradually to adapt mentally.



Graph 4. Discomfort while using the HMD Oculus Rift headgear
Source: Developed by the author.

CONCLUSIONS

This article addresses the didactic use of immersive virtual reality with the user's natural interaction focused on the inspection of wind-energy turbines. To do so, we propose a system in which the visualization technology (Oculus Rift), the acquisition of information (Kinect) and graphic software (Unity 3D) mainly converge. This system allows overcoming didactic obstacles identified by Flores *et al.* (2014) in subjects that, given their nature, generate physically hazardous situations and require industrial visits and knowledge of the field equipment. Such is the case of the subjects Introduction to wind-energy turbine technology and Seminar on wind-energy turbine technology of the Master's degree in Wind-energy Sciences at the Universidad del Istmo. It is worth mentioning that the use of immersive virtual reality in the wind-energy sector is currently being explored (ACCIONA, 2015; ACCIONA, 2016; CEMIE-Eólico, 2016), and this paper is an innovative didactic proposal that presents the technological convergence between virtual reality headgears and the user's natural interaction devices for the training in human resources in the sector.

According to the results of the first qualitative assessment of the use of the system and the application of the survey with a five-level Likert type items, it is possible to conclude that the immersion level perceived by the users is greater when using the HMD Oculus Rift headgear than when not. Furthermore, the sensation of experimenting total immersion in a virtual environment very similar to reality and the capacity to interact through body gestures motivated learning and the interest to carry out training practices with this technology positively.

The system proposed focuses on the inspection of wind-energy turbines to reinforce the learning of the key elements that intervene in the wind-energy generation process. However, the methodology proposed to achieve the technological convergence and the Oculus Rift, Kinect and Unity 3D software equipments may be used in the production of innovative didactic tools for subjects similar to those addressed in this article.

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