

ISSN 2523-6792

Volume 8, Issue 21 — e20240821 January — December — 2024

Journal of Technical Invention



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Journal of Technical Invention,
Volume 8, Issue 21: e20240821 January
– December 2024, is a Continuous
publication - Journal edited by
ECORFAN-Taiwan. Taiwan, Taipei.
YongHe district, ZhongXin, Street 69.
Postcode: 23445. WEB:
www.ecorfan.org/taiwan,
revista@ecorfan.org. Chief Editor:
GUZMÁN - HURTADO, Juan Luis.
PhD. ISSN-On line: 2523-6792.
Responsible for the latest update of this
number ECORFAN Computer Unit.
ESCAMILLA-BOUCHÁN, Imelda,
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December 31, 2024.

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Journal of Technical Invention

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Presentation of the content

In Issue 21 as the first article we present, *Comparison of methods for obtaining a hydroxyapatite and zinc oxide composite (HAp/ZnO)* by Dávalos-Rosas, Vivian Guadalupe, García-González, Nidia, Enríquez-Pérez, Ma. de los Ángeles and Castrejón-Sánchez, Víctor Hugo, with adscription in the Tecnológico de Estudios Superiores de Jocotitlán, in the next article we present, *Implementation of a system ANDON for the utilities department in a plastic injection plant* by Sotelo-Martínez, Samuel, Ocampo-Martínez, Rafael, Olivo-Flores, Marco Antonio and García-Mendoza, Rufino, with adscription in the Universidad Tecnológica de San Juan del Río, in the next article we present, *Desktop forklift simulator – DFS* by Juárez-Santiago, Brenda, Mendoza-Hernández, Guillermo, Ledesma-Uribe, Norma Alejandra and Santos-Osorio, Rene, with adscription in the Universidad Tecnológica de San Juan del Río, in the next article we present, *Speed control of 3 phase induction motor using an RC circuit as a start signal* by Juárez-Toledo, Carlos, Martínez-Carrillo, Irma, Hernández-Epigmenio, Miguel Ángel and Camacho- Altamirano, Ulices, with adscription in the Universidad Autónoma del Estado de México, in the last article we present, *Vivaldi antenna design and simulation with Bakelite substrate compared to RT duroid 5880 substrate* by Cruz-Orduña, María Inés, Ramos-González, Luz María, Benavides-Cruz, Alberto Manuel and Calderón-Sánchez, Javier, with adscription in the Universidad Tecnológica de San Juan del Río.

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Comparison of methods for obtaining a hydroxyapatite and zinc oxide composite (HAp/ZnO)

Comparación de métodos para la obtención de un compuesto de hidroxiapatita y óxido de zinc (HAp/ZnO)

Dávalos-Rosas, Vivian Guadalupe^a, García-González, Nidia^{*b}, Enríquez-Pérez, Ma. de los Ángeles^c and Castrejón-Sánchez, Víctor Hugo^d

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^d ROR Tecnológico de Estudios Superiores de Jocotitlán •  C-9077-2015 •  0000-0002-0112-5388 •  235470

CONAHCYT classification:

Area: Physics-Mathematics and Earth Sciences

Field: Physics

Discipline: Physics of the solid state

Subdiscipline: Composite materials

 <https://doi.org/10.35429/JOTI.2024.8.21.1.12>

Article History:

Received: January 13, 2024

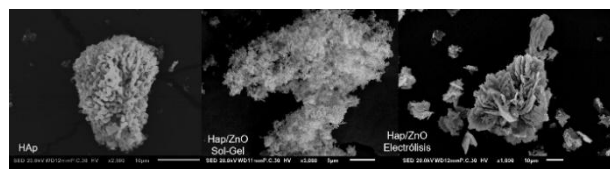
Accepted: December 31, 2024

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Abstract

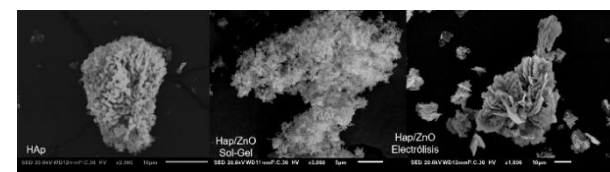
In this work, the synthesis of a composite material based on hydroxyapatite (HAp) and zinc oxide (ZnO) is reported. Two types of synthesis were evaluated, in order to know which of them allows to obtain a homogeneous composite material of HAp and ZnO, since making a composite material implies that two or more compounds must be integrated and do not separated; the HAp will be obtained from eggshell residue, ZnO will be synthesized by Sol-Gel and electrolysis; in the ZnO obtention, the previously synthesized HAp was incorporated and it is followed by a thermal treatment obtain the oxide. To evaluated the incorporation of ZnO with hydroxyapatite, Scanning Electron Microscopy, Elemental Analysis and Mapping by Energy Dispersive Spectrometry, Infrared Spectroscopy Analysis and X-ray Diffraction were performed. These two synthesis methods are aiming to obtain a homogeneous material, establishing a methodology to produce the material composite, as well as improve the photocatalytic properties.



Fintech, Transformation, Finance

Resumen

Este trabajo aborda la síntesis de un material compuesto con hidroxiapatita (HAp) y óxido de zinc (ZnO), se evaluarán dos tipos de síntesis para conocer cuál de ellas permite obtener un compuesto homogéneo de HAp y ZnO, ya que el hacer un compuesto implica que dos compuestos se integren sin separarse; la HAp se obtendrá del cascarón de huevo (residuo), el ZnO se obtendrá por síntesis Sol-Gel y electrólisis. Al realizar la síntesis del ZnO se incorporó la HAp previamente sintetizada y se dio el tratamiento térmico para obtener el óxido. Para evaluar la incorporación de ZnO en la HAp se realizó Microscopía Electrónica de Barrido, Análisis Elemental y Mapeo por espectrometría de Energía Dispersiva, Análisis de Espectroscopia de Infrarrojo y Difracción de rayos X. Al realizar estos métodos de síntesis se busca obtener un material homogéneo, establecer una metodología para obtener el compuesto y mejorar las propiedades fotocatalíticas.



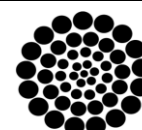
Fintech, Transformación, Finanzas

Citation: Dávalos-Rosas, Vivian Guadalupe, García-González, Nidia, Enríquez-Pérez, Ma. de los Ángeles and Castrejón-Sánchez, Víctor Hugo. [2024]. Comparison of methods for obtaining a hydroxyapatite and zinc oxide composite (HAp/ZnO). Journal of Technical Invention. 8[21]-1-12: e10811112.



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Introduction

Currently, it is important to search different chemical routes for material synthesis, this approach allows for the development of synthetic materials using methodologies that reduce or eliminate wastes, employing environmentally friendly processes. These materials can be used in various fields, such as photocatalysis, antibacterial materials, biomedical applications, among others (Marinas A., 2007), (Doria S., 2009), (Hernández L., M., & Prieto S., G., 2017).

Zinc oxide (ZnO) is a semiconductor with an exciton binding energy of 60 meV and a band gap energy of 3.37 eV, emitting exclusively in the UV range and exhibiting piezoelectricity. This oxide is biocompatible, making it suitable for biomedical, antibacterial, UV protection, optoelectronic, and catalysis applications (Wen, T., Gao, J., Shen, J., y Zhou, Z., 2001).

Hydroxyapatite (HAp) is basically composed of calcium and phosphorus, although depending on the synthesis method, it may contain traces of elements such as sodium and magnesium. One of the main characteristics of this material is the calcium-phosphorus molar ratio; the lower the ratio, the higher the acidity and solubility of the samples, which is also a factor related to the mechanical properties of the material. Pure-phase HAp has a Ca/P molar ratio of 1.67 and exhibits greater stiffness compared to HAp with a different molar ratio. When the ratio is 1.5, calcium-deficient samples are obtained, and if the molar ratio is higher than 1.67, it contains carbonate groups and traces of Mg. Additionally, HAp with molar ratios ranging from 1.5 to 2.0 has been used as ceramic coatings (Enríquez P. M. A., Castrejón S. V. H, Rosales D. J., Díaz C. F. J. A., 2020), (H. Dai, T. Xinwei, H. Zhu, T. Sun y X. Wang, 2018).

It is important to highlight that in the quest to improve various materials, oxide composites with supports or coupled materials have emerged, such as reinforced rubber, mortar and concrete, alloys, porous and fractured media, fiber composites, polycrystalline aggregates (metals), heterogeneous catalysts, and so on (Campbell, 2010), (Hashin, 1983).

Zinc oxide and hydroxyapatite have been integrated into composite materials (Sowińska-Baranowska, A., & Maciejewska, M., 2024) (Gupta, R., Singh, V. P., & Agarwal, M., 2024). In 2015, Ochoa-Fajardo D.A. synthesized a zinc oxide composite impregnated in a granular support that exhibited photocatalytic activity. The photocatalytic of ZnO was taken in advantage by using two granular supports (activated carbon and andesite) and two impregnation methods (controlled precipitation and solvent evaporation) (activated carbon and andesite) and two impregnation methods (controlled precipitation and solvent evaporation) (Fajardo, 2015). In 2016, Gálvez-Co et al. developed hydroxyapatite doped with ZnO nanoparticles for potential biomedical applications. Gálvez-Coy obtained natural hydroxyapatite from bone and studied the antimicrobial activity of the samples against *Pseudomonas aeruginosa* ATCC 9027 and *Staphylococcus aureus* ATCC 25923 (Gálvez-Coy, 2016). In 2019, Charlena *et al.* realized the synthesis and characterization of Zinc Oxide/Hydroxyapatite to obtain an antibacterial biomaterial. The hydroxyapatite was made from Snail shells (*Bellamya javanica*) due to their high calcium content, and the ZnO was synthesized using the low-temperature hydrothermal method (Charlena, Suparto, & Kurnia, 2019).

For photocatalysis, the formation of composites has been implemented, as modifying the properties of the main compound with another material can meet specific requirements. There are many methods available for the preparation of zinc oxide composites, which are divided into hydrochemical and pyrotechnical methods (Fajardo, 2015), (Iglesias-Juez, A., Kubacka, A., Colón, G., y Fernández-García, M., 2013), (Rashtiani, M., Ghasemi, E., Hallajian, S., & Ziyadi, H., 2024) (Das, A., Ringu, T., Ghosh, S., & Pramanik, N., 2024) (El Bekkali, C., Abadi, M., Labrag, J., Es-saidi, I., Robert, D., Nunzi, J. M., & Laghizil, A., 2024).

Among the hydrochemical and pyrotechnical methods for composite synthesis, notable techniques include solution impregnation (Zhong, J. B., Li, J. Z., He, X. Y., Zeng, J., Lu, Y., He, J. J., y Zhong, F., 2014), controlled precipitation (Ngo, G. V., Margailan, A., Villain, S., Leroux, C., y Bressy, C., 2013), microwave-assisted synthesis (Assi, N., Mohammadi, A., Sadr Manuchehri, Q., y Walker, R. B., 2014), hydrothermal deposition (Sahoo, T., Kim, M., Baek, J. H., Jeon, S. - R., Kim, J. S., Yu, Y. - T., ... Lee, I. -H., 2011), composite synthesis in emulsion (Lim, B. P., Wang, J., Ng, S. C., Chew, C. H., y Gan, L. M., 1998), mechanical mixing (Mohammadi, M., Sabbaghi, S., Sadeghi, H., Zerafat, M. M., y Pooladi, R., 2014), solvent evaporation (Shahid, M., McDonagh, A., Kim, J. H., y Shon, H. K., 2014), and physical vapor deposition (Thangadurai, P., Zergioti, I., Saranu, S., Chandrinou, C., Yang, Z., Tsoukalas, D., Boukos, N., 2011). In this work, hydroxyapatite was synthesized, zinc oxide was produced using sol-gel synthesis (Contreras-de La Cruz, M. A., García-González, N., Enríquez-Pérez, Ma. Ángeles And Castrejón-Sánchez, V. H., 2022) and electrolysis synthesis with zinc electrodes (Castrejón-Sánchez, V. H., Gacía-González, N., Enríquez-Pérez, Ma. Ángeles and Hernández-Bernardino, B., 2021), and hydroxyapatite was incorporated into the precursors of each zinc oxide synthesis.

Methodology

Materials

Eggshell, Hydrogen Peroxide (90%, Sigma Aldrich), Phosphoric Acid (85%, Sigma Aldrich), distilled water, zinc acetate, oxalic acid, sodium chloride.

Synthesis was carried out in two stages: in first stage, the materials were obtained separately. For second stage, the composite was prepared using sol-gel and electrolysis together. The methodology used is described below.

HAp Synthesis

For HAp synthesis, eggshells were collected, washed, and dried. They were treated with a 30% H_2O_2 solution at 95°C for 1 h, followed by washing the material with distilled water.

The material was dried at 80°C for 48 h. Subsequently, it was impregnated with 1M H_3PO_4 using the methodology proposed by Enríquez (Enríquez P. M. A., Castrejón S. V. H, Rosales D. J., Díaz C. F. J. A., 2020). The material was calcined at 800°C for 2 h.

ZnO Synthesis

Sol-Gel synthesis

Two solutions were prepared: Solution A: zinc acetate was dissolved in ethanol and heated to 60°C for 1 h. Solution B: oxalic acid was mixed in ethanol and heated to 50°C for 1 h; both solutions were stirred constantly. Solution A was added to Solution B, forming a gel, which was dried at 80°C for 20 h. Finally, the material underwent a thermal treatment at 650°C for 30 min, resulting in ZnO powders, which were labeled for characterization.

Electrolysis Synthesis

Sodium chloride was dissolved in water, and this solution was placed in an electrochemical cell, with zinc as both the anode and cathode. The solution was stirred for 30 min at 19 V and 0.33 Amp. The sample was then washed and filtered, followed by thermal treatment at 450°C for 2 h. The resulting ZnO was labeled for characterization.

Composite Synthesis

The composite was obtained by preparing HAp as described previously and it is pour into the electrochemical cell used for ZnO synthesis and the electrochemical process is repeated. The resulting material was then washed and filtered, followed by heat treatment for 2 h at 450°C, yielding a powder of the HAp/ZnO composite, which was labeled for characterization.

Sol-Gel Methodology

Zinc acetate was mixed with ethanol, and the solution was stirred and heated to 60°C for 45 min. HAp was then added, and the mixture was stirred for 15 min. Separately, a solution of oxalic acid with ethanol was prepared and stirred for one h at 50°C. Afterward, the two solutions were combined, forming a gel that was dried at 80°C for 20 h.

Finally, the obtained material was calcined at 650°C for 1 h, resulting in a powder.

The HAp/ZnO composite was labeled for characterization.

Electrolysis Synthesis

Sodium chloride and HAp were dissolved in water, and the solution was stirred for 30 min. The solution was placed in an electrochemical cell, where both the anode and cathode were zinc. The electrolysis process was carried out for 30 min, with the sample under constant stirring at 19 V and 0.33 amperes.

Material characterization

The characterization of HAp, ZnO, and the composites was carried out using the following techniques: X-Ray Diffraction (XRD) to determine the crystallographic planes of the material, using a Bruker DXR Discover D8 model, obtaining a diffractogram in the range from 15° to 90° range in 2 θ geometry. Fourier-Transform Infrared Spectroscopy (FTIR) was used to identify the functional groups present; a Perkin Elmer UART Two spectrophotometer was used, with spectra ranging from 4000 to 500 cm⁻¹. Scanning Electron Microscopy (SEM) was employed to analyze the morphology of the materials and their elemental composition via Energy Dispersive Spectroscopy (EDS), using a JEOL JSM-IT100 Scanning Electron Microscope coupled with a Bruker Nano D-12489 probe, operating at 20 kV acceleration voltage, high vacuum, and secondary electron signal.

Results and Discussion

In Figures 1 to 3, the micrographs of the individual components that compose the HAp/ZnO composite can be observed. The goal is to understand the effect that the synthesis process has on the morphology of each component and whether these morphologies are retained when the composite is obtained.

Figure 1 is a micrograph corresponding to HAp, which is the result of the chemical treatment with phosphoric acid and the subsequent heat treatment of calcium carbonate derived from eggshell.

The morphology of the HAp (which will serve as the composite's support) closely resembles coral, which has been previously reported (N. Mohan, R. P. F. B. Fernandez y H. Varm, 2018), (Contreras-de La Cruz, M. A., García-González, N., Enríquez-Pérez, Ma. Ángeles And Castrejón-Sánchez, V. H., 2022). According to Mohan et al. (N. Mohan, R. P. F. B. Fernandez y H. Varm, 2018), these types of porous morphologies are the result of the controlled evolution of CO₂ gas during the reaction between calcium carbonate and the phosphate group in the phosphoric acid solution.

Box 1

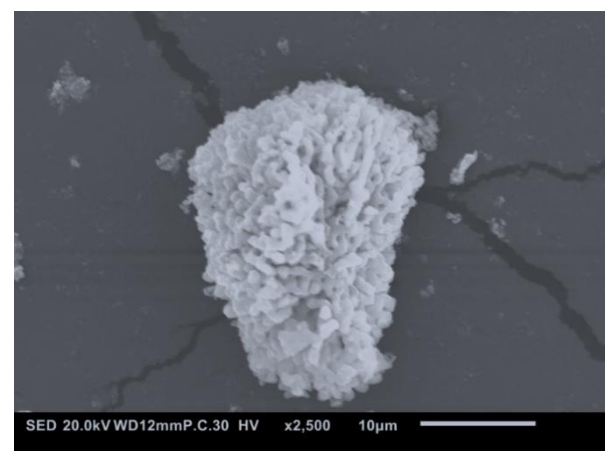


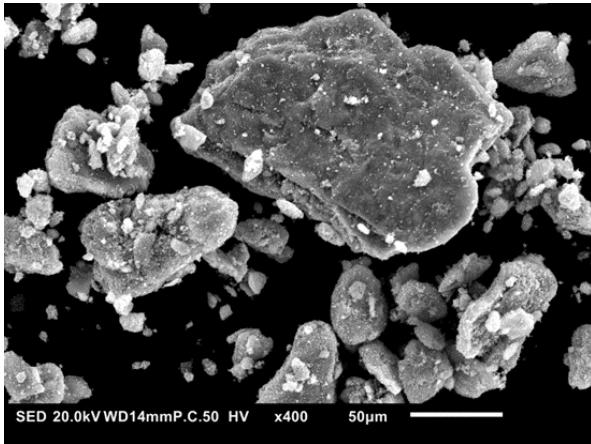
Figure 1

Hydroxyapatite Micrograph

Source: own elaboration

The sol-gel process allowed to produce a particulate material that does not exhibit a predominant morphology (Figure 2).

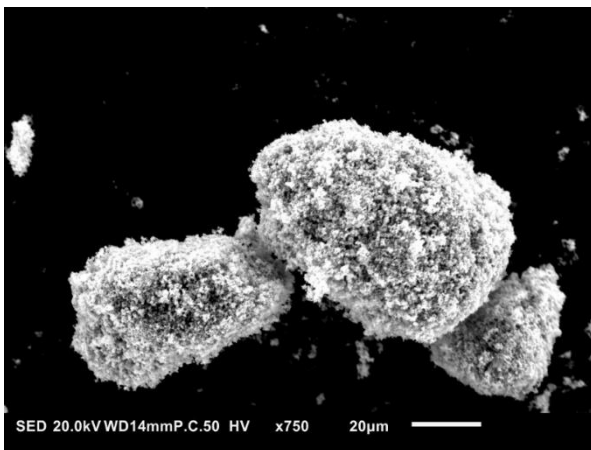
The ZnO particles show relatively flat and continuous surfaces, which may present a clear disadvantage in the photocatalysis process in which they will be used. The particle sizes obtained through this method range from 15 to approximately 175 μm .

Box 2**Figure 2**

ZnO Sol-Gel Micrograph

Source: own elaboration

The ZnO obtained by electrolysis (Figure 3) exhibits a highly irregular surface and appears to be quite porous. This characteristic could be an advantage for ZnO, as in the photocatalytic processes where it will be used, porosity is accompanied by a larger surface area compared to a material with a continuous surface. The size of the ZnO particles ranges from 40 to 70 μm .

Box 3**Figure 3**

ZnO Electrolysis Micrograph

*Source: own elaboration**Elemental Analysis*

Energy Dispersive Spectroscopy (EDS) was performed to analyze the elemental composition of the composites and individual compounds. When comparing the atomic percentages of the individual components, the ZnO synthesized by electrolysis is very similar to that obtained by sol-gel synthesis, with stoichiometries close to the 1:1 atomic ratio.

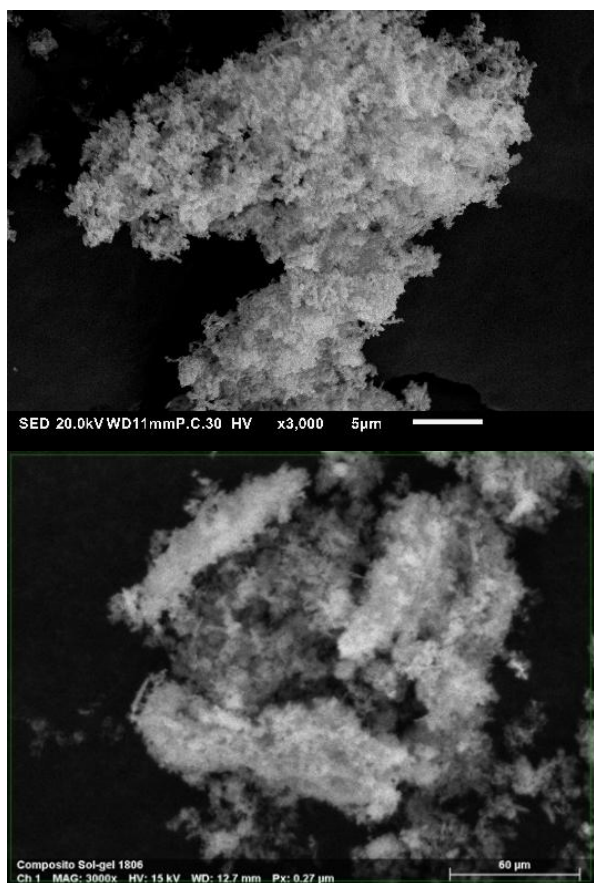
The atomic Ca/P ratio for HAp is 38.11, in the Sol-Gel composites it was 8.91, and 66.25 for Electrolysis, respectively; this ratio increases with the rise in carbonate ion content, as the CO_3^{2-} ion replaces PO_4^{3-} (Ochoa I., López E., Copete H., 2021), these ratios indicate that the hydroxyapatite is both hydroxylated and carbonated (Markovic, M., Fowler, B. O., & Tung, M. S., 2004).

Additionally, the Ca/Zn ratio in the composites was calculated, with a value of 2.38 for Sol-Gel, indicating that there are approximately two Ca atoms for each Zn atom. For Electrolysis, the ratio is 33.13, meaning there are approximately 33 Ca atoms for each Zn atom. These ratios are associated with the formation of composites (Contreras-de La Cruz, M. A., García-González, N., Enríquez-Pérez, Ma. Ángeles And Castrejón-Sánchez, V. H., 2022).

In the composites, it is observed that zinc decreases according to the type of synthesis having 3.04% At. for HAp/ZnO Sol-Gel and 0.4% At. for ZnO/HAp Electrolysis. We assume that it is because the sol-gel technique allows better incorporation between ZnO and HAp.

Sol-Gel Composite

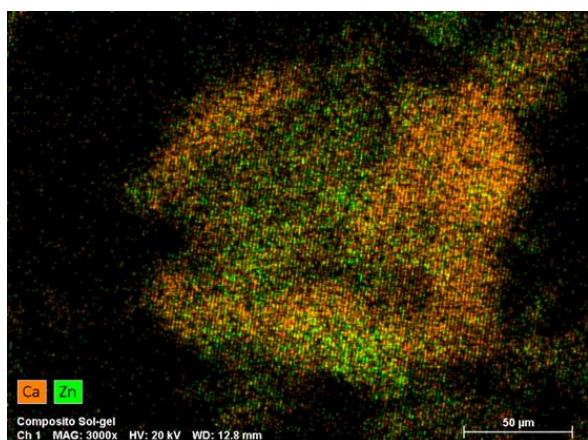
Figure 4 corresponds to the HAp composite with ZnO obtained by sol-gel. The displayed morphology for this material appears without a defined structure, differing significantly from the morphologies of the individual HAp and ZnO components (Figures 1 and 2, respectively). A surface mapping of the particle was conducted to determine the distribution of ZnO on the HAp support (Figure 5), where the green color is associated with Zn from ZnO and the orange with Ca from CaCO_3 .

Box 4**Figure 4**

HAp/ZnO Sol-Gel Micrograph

Source: own elaboration

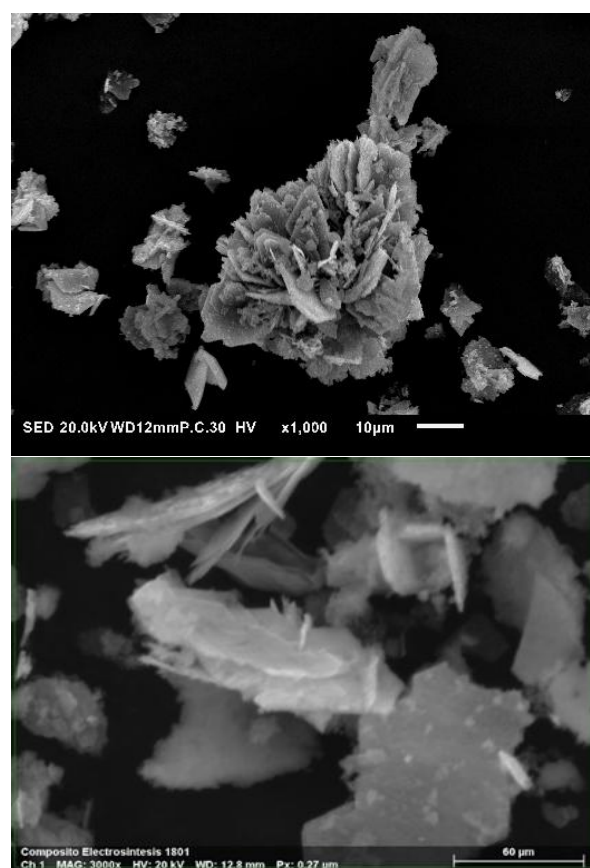
It is evident that the distribution of ZnO on the surface of CaCO_3 is quite homogeneous, as shown in Figure 5. The micrograph's background was removed to make the distribution of the elements clearer.

Box 5**Figure 5**

HAp/ZnO Sol-Gel Mapping

*Source: own elaboration**Electrosynthesis Composite*

For the composite obtained through electrosynthesis, elemental mapping was also performed, like the previous composite. In the micrograph in Figure 6, the morphology of the HAp/ZnO composite can be observed. In this case, the morphology resembles flakes, which is very different from the morphology of both HAp and ZnO.

Box 6**Figure 6**

HAp/ZnO Electrolysis Micrograph

Source: own elaboration

Figure 7 represents the distribution of ZnO (green) on the HAp support indicated in orange, which shows that the distribution of ZnO on the surface of HAp is less homogeneous than in the previous case, as there are many areas of HAp (orange) without ZnO on its surface. To improve the visualization of the compounds' distribution, the background micrograph in Figure 7 was removed.

Box 8

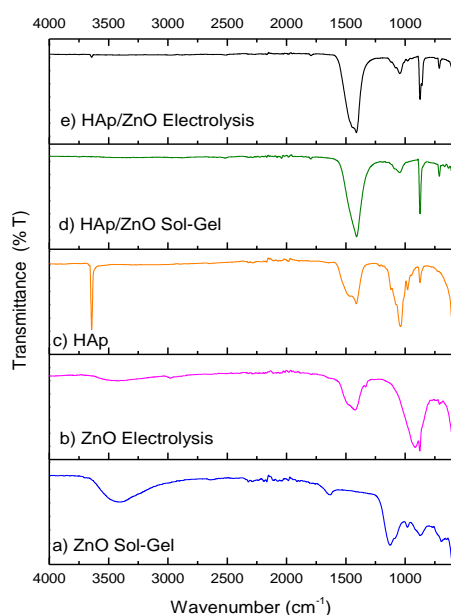


Figure 8

Spectra of FTIR

Source: own elaboration

Box 7

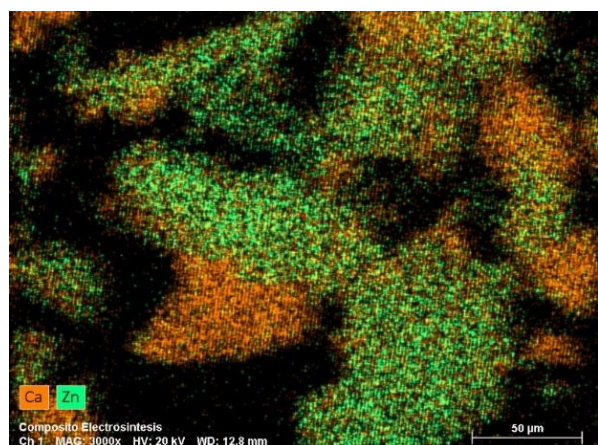


Figure 7

HAp/ZnO Electrolysis Mapping

Source: own elaboration

FTIR Spectroscopy

Figure 8 shows the FTIR spectra of the samples. Both techniques confirm the formation of ZnO, with small shifts in the absorptions.

When ZnO is prepared by sol-gel, the peaks at 3404 cm^{-1} and 1651 cm^{-1} correspond to OH stretching vibrations and bending modes of absorbed water (Sowri, Ramachandra, Sujatha, Venugopal, & Mallika, 2013).

The vibrations at 1131 cm^{-1} , 966 cm^{-1} , 883 cm^{-1} , and 646 cm^{-1} are due to the tension of the Zn-O bond, indicating the formation of ZnO (Awasthi, Adhikari, Ko, Park, & Kim, 2016) (Galindo G., Fortis H., De La Rosa R., Zermeño G., & Galindo G., 2022), (Maher, S.; Nisar, S.; Muhammad A., S.; Saleem, F.; Behlil, F.; Imran, M.; Assiri, M. A.; Nouroz, A.; Naheed, N.; Khan, Z. A.; Aslam, P., 2023).

By electrolysis (Figure 8b), the signal at 3456 cm^{-1} , which corresponds to the OH bending stretch of absorbed water (Sowri, Ramachandra, Sujatha, Venugopal, & Mallika, 2013), is predominant. The Zn-O bond tension is observed at 914 cm^{-1} , 873 cm^{-1} , and 705 cm^{-1} , characteristic signals of ZnO formation (Faria, y otros, 2022). We assume that these shifts are due to the fact that the precursors used in this synthesis cannot be completely eliminated.

In Figure 8c, the peak at 3632 cm^{-1} corresponds to the stretching of the hydroxyl group associated with the OH group of HAp. The absorption at 1412 cm^{-1} is due to the presence of carbonate groups, and at 1040 cm^{-1} , characteristic of phosphate groups. The signal at 880 cm^{-1} is attributed to the presence of both carbonate and phosphate groups, characteristic signals of HAp (Adeogun, y otros, 2018).

The ZnO/HAp composite, regardless of the preparation technique, essentially shows the same signals with slight shifts (see Figures 8d and 8e). The presence of ZnO influences the vibrations of HAp due to steric hindrances, leading to a reduction in the vibrational energy of the HAp molecule (Molodovan M, 2015).

The intensity of the 3632 cm^{-1} band decreases because of the interaction between ZnO and the OH groups of HAp (Charlena, Suparto, & Kurnia, 2019); the absorption of carbonate groups at 1420 and 833 cm^{-1} is more intense due to the interaction between the materials (Azam A, 2012), (Molodovan M, 2015). The absorption at 1019 cm^{-1} , attributed to phosphate groups, decreases because of the interaction between ZnO and PO_4 , indicating that HAp is influenced by Zn (Molodovan M, 2015) (Charlena, Suparto, & Kurnia, 2019). The absorption bands of ZnO present in the material before mixing with HAp do not appear in the FTIR spectrum, except for a band at 646 cm^{-1} at lower wavenumbers.

The prepared composites exhibit homogeneity, this means that ZnO and HAp are well combined (Charlena, Suparto, & Kurnia, 2019) (Azam A, 2012).

X-ray diffraction

Figure 9 shows the results for X-Ray Diffraction analysis of the composites (HAp/ZnO Sol-Gel and ZnO/HAp Electrolysis) and the precursors HAp, ZnO Sol-Gel, and ZnO Electrolysis.

The ZnO (Figure 9a and 9b) displays 2θ peaks at 31.9° , 34.6° , 36.4° , 47.8° , 56.8° , 68.3° , and 69.4° , with their respective diffraction planes (-100), (00-2), (-10-1), (-10-2), (-210), (-21-2), and (-20-1), respectively. These angles are characteristic of the hexagonal Wurtzite phase of ZnO previously reported (Alami, Z., Salem, M., Gaidi, M., & Elkham, J., 2015), (Baneto, M., Enesca, A., Lare, Y., Jondo, K., Napo, K., & Duta, A., 2014), (Carta de difracción COD-2300113, Sowa Heidrun, Ahsbahs Hans, 2006).

Figure 9c shows the diffractogram of HAp, with the peaks at 2θ angles of 19.6° , 28.99° , 46.66° , 51.1° , 54.7° , and 63° , along with their respective reported diffraction planes (El hadad, A. A.; Barranco, V.; Jiménez M., A. ; Peon, E.; Galván, J. C., 2010), (Hendricks S., Jefferson M., Mosley V., 1932), (Carta de Difracción COD 1100066: $\text{Al}_2\text{O}_3\text{-ZrO}_2$ standar).

Since it is a carbonated HAp, it is possible that Zn ions occupy the sites corresponding to the CO_3^{2-} y PO_4^{3-} ions. When HAp and ZnO are coupled, the signals become broader, and the intensity increases (see Figure 9d and 9e). Contreras-de La Cruz, M. *et Al.* (Contreras-de La Cruz, M. A., García-González, N., Enríquez-Pérez, Ma. Ángeles And Castrejón-Sánchez, V. H., 2022) also confirmed that both signals shift slightly, which is also observed in the infrared spectrum (Figure 8d and 8e).

Box 9

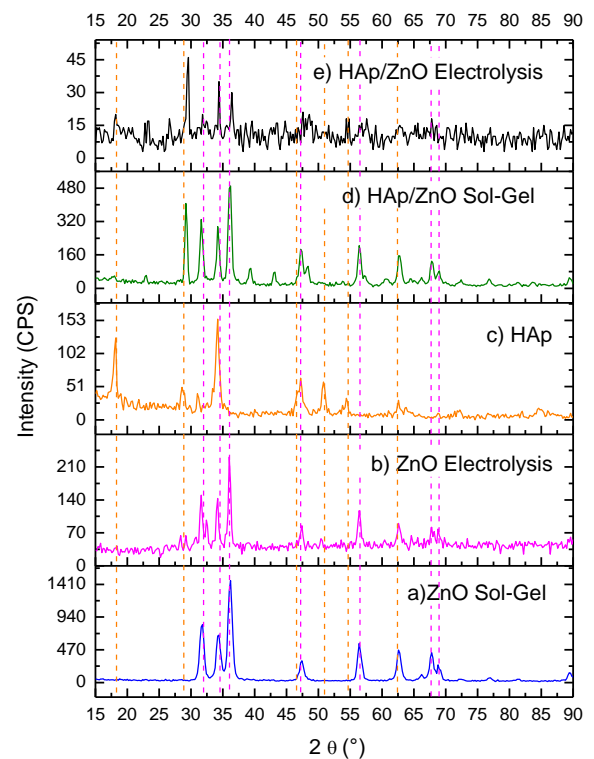


Figure 9

Diffractograms

Source: own elaboration

Conclusions

The HAp/ZnO composite was obtained through two synthesis routes (Sol-Gel and Electrolysis); to achieve homogeneity, hydroxyapatite was added during the preparation of the ZnO precursor, followed by a thermal treatment.

In the scanning electron microscopy images, the influence of the synthesis method on morphology is evident. Through electrolysis, the formation of agglomerated sheets is observed, whereas in the Sol-Gel method, no defined morphology is seen, and only pores are observed, which could facilitate the photocatalytic process. The elemental analysis allowed the quantification of the atomic percentages of each composite, showing that the Zinc drastically decreases in the Electrolysis composite (0.4% At) in comparison with the Sol-Gel composite with a Zn content of 3.04% At. The mapping shows that Zn and Ca are homogeneously distributed, where Zn associated with ZnO and Ca with HAp.

Infrared spectroscopy confirmed the formation of both composites; however, it is not possible to distinguish between them.

The X-ray diffraction analysis confirmed the presence of HAp and ZnO in both composites. The crystallinity of the Electrolysis composite decreased, which may be associated with the morphological changes and the reduction in the atomic percentage of Zn.

Declarations

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Author contribution

Dávalos-Rosas, V. G.: Contributed to the synthesis of the materials studied in the article.

García-González, N.: Contributed to the project idea, the characterization, and the discussion of the results of the materials studied in the article.

Enríquez-Pérez, Ma. Angeles: Contributed to the project idea, the characterization, and the discussion of the results of the materials studied in the article.

Castrejón-Sánchez, V.H.: Contributed to the project idea, the characterization, and the discussion of the results of the materials studied in the article.

Availability of data and materials

The synthesized materials and all the data from the analyses carried out in this research are available.

Funding

We thank TecNM for the financial support through “Convocatoria 2024 Proyectos de Investigación Científica, Desarrollo Tecnológico e Innovación”.

Acknowledgements

The authors thank the Academy-Industry Cooperation Center of the Tecnológico de Estudios Superiores de Jocotitlán for all the support provided through access to the XRD, FTIR, SEM and EDS equipment.

Abbreviations

DXR	X-ray diffraction
EDS	Energy Dispersive Spectroscopy
FTIR	Fourier Transform Infrared Spectroscopy
HAp/ZnO Electrolysis	Composite synthesized by Electrolysis.
HAp/ZnO Sol-Gel	Composite synthesized by Sol-Gel.
HAp	Hydroxyapatite
SEM	Scanning Electron Microscopy.
ZnO	Zinc Oxide

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Implementation of a system ANDON for the utilities department in a plastic injection plant

Desarrollo de un sistema ANDON para el área de servicios en planta de inyección de plástico

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CONAHCYT classification:

Area: Engineering
 Field: Engineering
 Discipline: Electronic Engineering
 Subdiscipline: Automation and Control

<https://doi.org/10.35429/JOTI.2024.8.21.1.7>

Article History:

Received: January 23, 2024
 Accepted: December 31, 2024



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Abstract

ANDON systems have been very useful in different industrial processes, since through visual management they alert in real time about present problems, reducing response time, downtime and increasing efficiency. These systems are generally manual and depend on the manipulation of operators; their operation is desired to be automatic; this can be achieved using elements that capture process variables and programmable controllers and display elements. This work presents an application in a plastic injection company to solve a problem of monitoring pressure and temperature services that caused downtime in production lines. The use of sensors is proposed for the acquisition of variables and screens to present information through visualization tools available in PLC for remote monitoring, acquisition and presentation of data so that solutions can be applied immediately, reducing downtime. and saving costs.

Resumen

Los sistemas ANDON han resultado muy útiles en distintos procesos industriales, ya que a través de una gestión visual alertan en tiempo real sobre los problemas presentes, reduciendo el tiempo de respuesta, tiempos de inactividad e incrementando la eficiencia. Estos sistemas generalmente son manuales y dependen de la manipulación de los operadores, se desea que su funcionamiento sea automático, esto se puede lograr utilizando elementos captadores de variables del proceso y controladores programables y elementos de visualización. Este trabajo presenta una aplicación en una empresa de inyección de plástico para resolver un problema de monitoreo de servicios de presión y temperatura que provocaba tiempos de paro en líneas de producción. Se propone el uso de sensores para la adquisición de variables y pantallas para presentar la información a través de herramientas de visualización disponibles en PLC para el monitoreo, adquisición y presentación de datos a distancia para que las soluciones puedan aplicarse inmediatamente, reduciendo el tiempo de inactividad y ahorrando costos.

Objectives	Methodology	Contribution
 Monitor process variables Automatic data presentation Prevent failures	 Needs diagnosis System development Results evaluation	 Link school with company Train operation workers Improve performance and save costs

Objetivos	Metodología	Contribuciones
 Monitorear variables de proceso Presentacion autonoma de datos Prevenir fallas	 Diagnostico de necesidades Desarrollo del sistema Evaluación de resultados	 Vincular escuela empresa Capacitar personal de operación Mejorar desempeño y ahorrar gastos

Monitoring, PLC, System

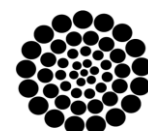
Monitoreo, PLC, Sistema

Citation: Sotelo-Martínez, Samuel, Ocampo-Martínez, Rafael, Olivo-Flores, Marco Antonio and García-Mendoza, Rufino. [2024]. Implementation of a system ANDON for the utilities department in a plastic injection plant. Journal of Technical Invention. 8[21]-1-7: e20811107.



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Introduction

ANDON is a visual and auditory communication system used in industry that informs operators which activities they need to perform to resolve problems in the production line as soon as they occur, to increase quality, production, and reduce costs [1]. First used in Japan in 1970, these systems support decision-making in lean manufacturing and are applied in industry at different levels: manual, semi-automatic, and fully automated. In addition, they are classified by the type of information they provide, such as process status information, product quality information, and operator safety information [2].

Researchers in industrial processes have presented work analyzing three fundamental Lean Manufacturing tools: Visual Management, Poka Yoke, and the ANDON system, which help in the production process by preventing errors in the manufacturing industry, concluding that these three tools positively impact economic sustainability [3].

Box 1



Figure 1

Industrial ANDON type signal tower.

Applications with manual ANDON systems limit response time and rely entirely on the operator's interpretation and evaluation of problems, which is not always the most efficient and timely. Additionally, these systems generally display the error or failure signal after the issue has occurred, necessitating corrective maintenance and process recovery to resume production, resulting in production downtime.

Therefore, the development of an automatic ANDON system application is presented, which displays process status information for different areas of the plant.

This system allows the identification or visualization of undesirable trends before announcing a failure signal, consequently enabling corrective action to be taken to prevent downtime. Previous work has taken the basic principle of the ANDON system but modified it by incorporating computer assistance. Due to the industrial plant's infrastructure, the visibility of indicator lights can be challenging, so an auxiliary department for handling process status signals has been implemented, consequently improving plant performance [4].

This project was developed for an automotive parts company. Air compression, chiller water condensation, and cooling tower operations are essential services required for the proper operation of the injection and blow molding process. In the plant layout, the service area is located outside the injection plant, and it is important to constantly monitor these services in real time from the maintenance area to prevent a service failure that could cause partial or total production downtime. This design addresses monitoring and downtime issues. It acquires pressure and temperature readings and utilizes an Ethernet (EtherCAT) fieldbus available in the plant as a communication medium to collect and display the value of these variables in real time anywhere within the plant. This protocol is one of the new real-time Master/Slave functionality networks, with an open standard capable of handling up to 1000 I/O points within 30 μ s response time. Using twisted pair or fiber optic cables in Full Duplex communication, it achieves >90% efficiency with a speed of 200 Mbits/s [5].

The ANDON system is enhanced by combining it with other technologies such as programmable logic controllers (PLCs), resulting in projects enabling continuous process monitoring. Using predictive maintenance, these projects maintain production volume and prevent downtime [6]. For this designed system, a Beckhoff PLC was used, a brand that offers visualization tools for creating control panels.

The document is structured into five sections. Section II details the automatic ANDON system, including a comprehensive description of its components. Section III outlines the complete functional architecture of the system through a block diagram. Sections IV and V subsequently present the empirical results and their respective analyses and conclusions.

Integration of the ANDON System

In designing this project, various elements comprise the ANDON system are considered. The HMI (Human-Machine Interface) will utilize a commercial monitor to display process data to users. In addition, this monitor includes a touch screen, allowing control of the system's start and stop operations. The design of this interface must be intuitive, efficient, and user-friendly, combining user needs with machine capabilities [7].

The sensors interact with the process variables and provide a proportional electrical signal as input to the control system. Three J type thermocouples and a GP-M series pressure sensor from Keyence will be used. The supervisory system will be a computer responsible for collecting process data and sending instructions via the command line. For this project, the computer can be online with the system and perform supervisory functions; however, the system can operate independently of the computer. The PLC, or programmable logic controller, will host the control program and act as the field device receiving the signals from the field sensors, properly formatting these signals, and displaying the data on a visualization panel. A Beckhoff PLC, model CX9020, will be used. This controller features a 1GHz ARM Cortex-A8 processor, an embedded Windows 7 operating system, and communication peripherals including RJ45, DVI-D, and USB [8]. This model is suitable for the application as it natively includes a visualization tool that allows the creation of control panels through the TwinCAT program.

Box 2

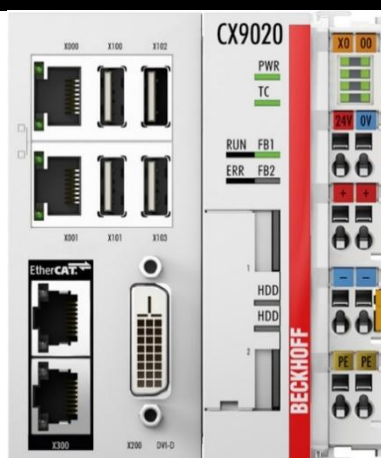


Figure 2

PLC Beckhoff CX9020

Next, a communication network is necessary to link the PLC with the computer, HMI, and other devices within the plant network. This project uses the EtherCAT (Ethernet for Control Automation Technology) protocol, an Ethernet-based fieldbus developed by Beckhoff Automation. It is designed for fast response control applications, featuring a synchronized, deterministic, and real-time protocol that maintains a high speed of 100 Mbps and short communication cycles of 12 μ s. It employs a master-slave communication model [9]. For this project, only one master device containing the programmable logic will be used.

Box 3

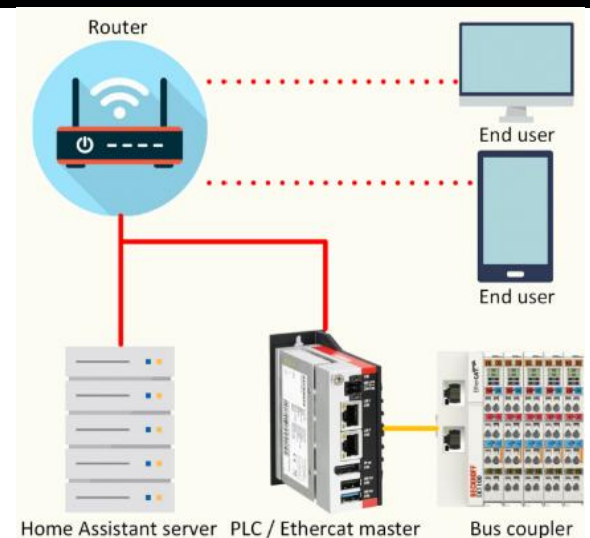


Figure 3

Integration of the ANDON System

The integration of the proposed ANDON system is shown in Figure 3. The process variable sensing elements, such as thermocouples and pressure sensors, are linked to the PLC controller via a bus coupler equipped with cards for processing digital and analog I/O signals. The dedicated controller receives the input signals and updates the control outputs based on the user-developed program. The generated data is transmitted through the EtherCAT network, which is compatible with the plant's Ethernet server network. Once on the network, the data can be accessed by the end user via wired or wireless means through an interconnection device like a router.

Configuration and Operation of the ANDON System

The PLC peripheral connections include:

Digital Inputs: Three digital inputs for start, stop buttons, and an auxiliary contact for power supply failure detection.

Digital Outputs: Four digital outputs for red, yellow, green, and blue lamps.

Analog Inputs: One analog input for the compressor pressure sensor with a standard signal of 0 to 10 V, proportional from -0.21 to 1 MPa, and three analog inputs for J type thermocouples to measure ambient temperature, chiller temperature, and cooling tower temperature.

Temperature readings are performed using the EL3318 module, which is a specialized module for connecting to eight thermocouples, featuring 16-bit resolution, automatic linearization, and cold junction compensation.

Box 4

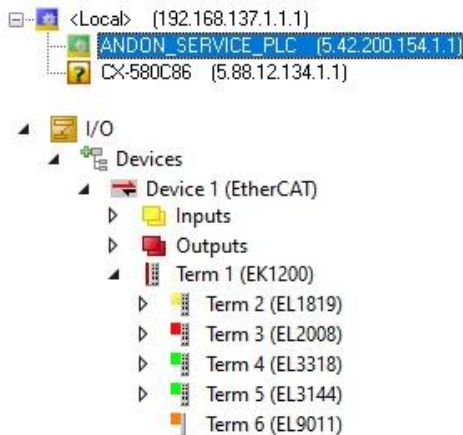


Figure 4

Network and Communication Bus Configuration.

The PLC controller is configured on the industrial Ethernet network by assigning parameters such as name, connection time, and a static IP address within the same subnet to join the network. The procedure for incorporating the device into the network is based on commonly used protocols for integrating automation systems into control networks [10].

The variables used in the ladder logic programming for receiving and generating control signals are registered. Depending on their nature, these variables are declared as integers, Booleans, and real numbers. See Figure 5 for a detailed view of the ANDON system variables.

Box 5

andon.programa.control			
Expression	Type	Value	Address
presion	INT	9475	%I*
chiller	INT	629	%I*
torre	INT	488	%I*
ambiente	INT	482	%I*
lamp_verde	BOOL	TRUE	%Q*
lamp_ambar	BOOL	FALSE	%Q*
lamp_roja	BOOL	FALSE	%Q*
compresor_apagado	BOOL	TRUE	%I*
inicio	BOOL	FALSE	%M*
paro	BOOL	FALSE	%M*
presion_escalada	REAL	5.78325748	%M*
chiller_escalada	REAL	10.5633583	%M*
torre_escalada	REAL	21.9647751	%M*
ambiente_escalada	REAL	23.8292141	%M*

Figure 5

ANDON System Variables

During the execution of the ANDON system, the variables are assigned a name, type, value, and memory address. The user interaction indicators of the ANDON system are configured according to the values required by the process. For the compressor pressure, the minimum value is 5.5 Bar, and the maximum is 7.5 Bar. The expected temperature for the chiller is a minimum of 7°C and a maximum of 16°C, while the cooling tower temperature should be between 12°C and 28°C. Ambient temperature does not have comparison parameters and is used exclusively for monitoring, as it depends on the time of day and climatic conditions.

The programming logic used in the controller for the operation of the designed ANDON system is represented in the diagram in Figure 6. In this diagram, a red lamp lights up when a compressor power supply failure is detected, a yellow lamp lights up when there is a failure in reading any of the variables, a green lamp lights up when at least one of the variables is outside the desired preset range, and finally, a blue lamp lights up to indicate that the pressure and temperature parameters are within the normal range. This logic executes sequentially if the start button is activated.

Box 6

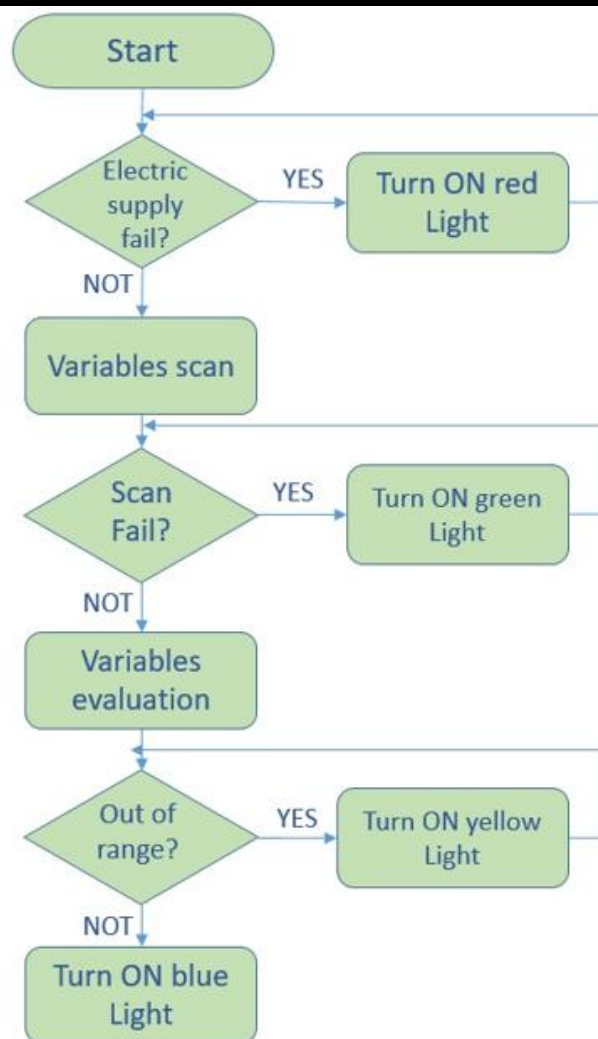


Figure 6

ANDON System Operation Diagram

Finally, the performance of the ANDON system is not only displayed via the local signal tower but also displayed onto a monitor via a digital HMI control panel designed with the TwinCAT tool. This tool allows for the creation of graphics linked to process variables, which can be made available as a web page. This enables remote monitoring and operation over the internet from various network access points.

Results

The final design of the ANDON system visualization, operating and running online, is shown in Figure 7. This graphic can be accessed by any internet-connected device for remote monitoring and operation.

Box 7



Figure 7

ANDON System Graphical Panel.

Access to this graphic is available from any point in the production plant via screens that display graphs and numerical indicators showing real-time values of process variables. After installing the system in the service area of the injection plant, tests were conducted to compare the values provided by the ANDON system with those obtained from calibrated measurement instruments, yielding results as shown in Table 1.

Box 8

Table 1

ANDON System Test Measurements vs. Calibrated Instruments

Hora	Presión Compresor		Temperatura Chiller		Temperatura Torre		Temperatura Ambiente	
	ANDON	Real	ANDON	Real	ANDON	Real	ANDON	Real
8:00	6.2 Bar	6.2 Bar	8.1 °C	8.4 °C	15.5 °C	15.7 °C	18.5 °C	18.7 °C
9:00	6.1 Bar	6.0 Bar	8.5 °C	8.9 °C	17.2 °C	17.5 °C	29.2 °C	29.5 °C
10:00	6.0 Bar	5.9 Bar	9.1 °C	9.3 °C	18.9 °C	19.1 °C	20.4 °C	20.9 °C
11:00	5.9 Bar	5.7 Bar	9.7 °C	10.0 °C	20.6 °C	20.9 °C	21.6 °C	22.0 °C
12:00	5.8 Bar	5.6 Bar	10.5 °C	10.8 °C	21.9 °C	22.3 °C	23.9 °C	24.2 °C
13:00	5.8 Bar	5.7 Bar	11.0 °C	11.4 °C	22.2 °C	22.6 °C	25.3 °C	25.6 °C
14:00	5.9 Bar	5.8 Bar	12.3 °C	12.8 °C	23.3 °C	23.8 °C	27.1 °C	27.4 °C
15:00	6.0 Bar	5.8 Bar	12.9 °C	13.5 °C	24.2 °C	24.6 °C	29.7 °C	30.3 °C

Source: Own elaboration

To verify the effectiveness of this system, the relative error between the values obtained by the ANDON system and the expected values measured with instruments is calculated. The following formula is used to calculate this parameter:

$$er = \frac{\sum_{i=0}^n \left| \frac{X_i - X_v}{X_v} \right|}{n} \quad (1)$$

Where:

n = total number of data points

Xi = value acquired in each iteration.

Xv = expected value.

The relative error for each variable was 0.0304 for pressure, 0.0330 for chiller temperature, 0.01595 for cooling tower temperature, and 0.01564 for ambient temperature. This demonstrates that the proposed system has a sampling accuracy between 96% and 98%.

Conclusions

This article demonstrates the implementation of an automatic ANDON system for monitoring process variables. The data acquisition system is implemented in a PLC controller with a bus coupler to receive pressure and temperature data. Information is transmitted over an Ethernet network and displayed on screens to the end user for the prevention of failures and downtime.

By utilizing the EtherCAT protocol, the system benefits from high transmission speed and low latency. Additionally, the system can integrate a database for information storage and historical data retrieval.

The system was verified by calculating the relative error between the obtained values and the expected values, demonstrating a sampling accuracy between 96% and 98%. It is validated that the system can be applied to other areas of the plant with different process variables.

Declarations

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Author contribution

Sotelo Martínez, Samuel: Contributed to the project idea, design, implementation and installation of the project in the company's plant.

Ocampo Martínez, Rafael: Contributed to the technical advice, research method and project documentation.

Olivo Flores, Marco Antonio: Contributed to design validation, research method and translation support.

García Mendoza, Rufino: Contributed to methodological review, project monitoring and technique advice.

Availability of data and materials

The values presented in section VI were measured on March 14, 2024. The availability of this data is reserved for the authorization of the company.

Funding

The project was financed by two collaborators: the material and equipment by the company EXO-S and the design, development and installation by the university UTSJR.

Acknowledgements.

We would like to extend our special thanks to EXO-S Industries for allowing the development of the project within their facilities and for providing the necessary materials, tools, equipment, and infrastructure for the implementation of the project.

Abbreviations

EtherCAT: Ethernet for Control Automation Technology

HMI: Human Machine Interface

Mbps: Mega Bits per Second

PLC: Programmable Logic Controller

USB: Universal Serial Bus

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Desktop forklift simulator - DFS

Simulador de montacargas de escritorio - SME

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CONAHCYT classification:

Area: Engineering
 Field: Technological sciences
 Discipline: Computer Technology
 Subdiscipline: Computer aided teaching

<https://doi.org/10.35429/JOTI.2024.8.21.3.9>

Article History:

Received: January 27, 2024
 Accepted: December 31, 2024



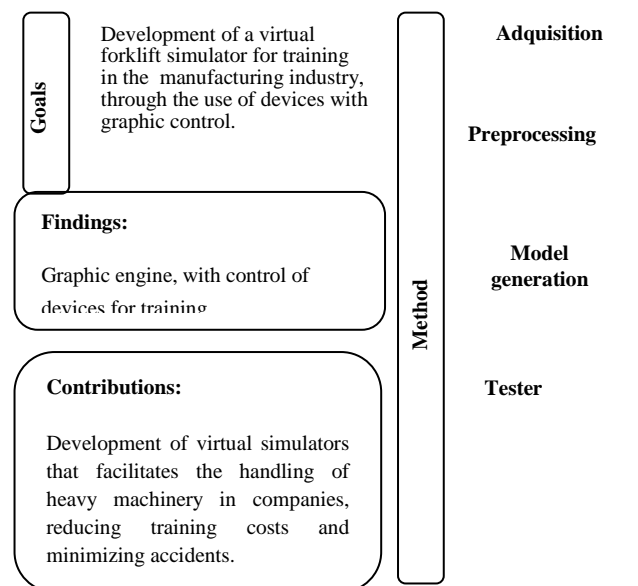
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Abstract

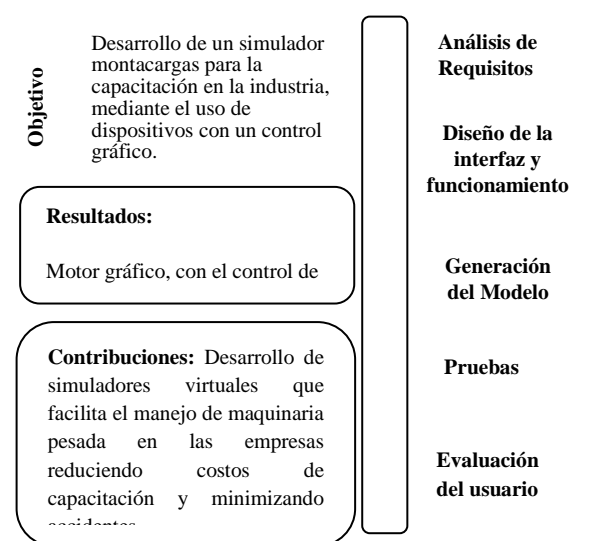
This article presents the design and development of a technological tool that has the function of a forklift simulator, which is an interactive desktop application, and the objective is to train personnel in the use of a forklift car, to prevent accidents and major injuries. reliability in the mobility process when driving in real time: the methodology used is scrum to generate a software product with compliance with the industry requirements, which is carried out through a product backlog, and sprints to carry out the deliverables of the simulator modules, the result obtained was a graphic engine of Unreal Engine 5 and Blender for modeling, where the connection of devices is made, the control with steering wheel, pedals and gear lever is generated.

Resumen

Este artículo presenta el diseño y desarrollo de una herramienta tecnológica que tiene la función de un simulador de montacargas, la cual es una aplicación de escritorio interactiva, y el objetivo es poder capacitar personal en el uso de un carro montacargas, para prevenir accidentes y mayor confiabilidad en el proceso de la movilidad al conducir en tiempo real: la metodología utilizada es scrum para generar un producto de software con el cumplimiento de los requerimientos de la industria, la cual se realiza mediante un product backlog, y sprints para realizar los entregables de los módulos del simulador, el resultado obtenido fue un motor gráfico de Unreal Engine 5 y Blender para el modelado, en donde se realiza la conexión de dispositivos se genera el control con volante, pedales y palanca de velocidades.



Forklift, Simulator, Training, Unreal engine, Control



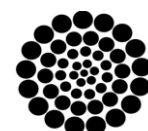
Montacargas, Simulador, Unreal Engine Control

Citation: Juárez-Santiago, Brenda, Mendoza-Hernández, Guillermo, Ledesma-Uribe, Norma Alejandra and Santos-Osorio, Rene. [2024]. Desktop forklift simulator - DFS. Journal of Technical Invention. 8[21]-1-9: e30821109.



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Introduction

In the area of engineering and technology as well as innovation It is still transforming the way we approach industrial challenges. The development of innovative solutions is a key element to power operating efficiency and also to improve security standards in a work environment.

This project developed a technological solution that uses a simulator in a format of a local desktop application which controls a wheel decive and pedals for videogames.

The use of cutting edge technology, is essential in industry in order to train new operators who work in high-risk activities.

Tho technology will be also be able to interact with more decives in real time.

This project was created by using Blender and Unreal Engine software.

Blender and Unreal Engine allowed us to generate functionality on every device connected to the software all together working to simulate a lift fork.

Manufacturing industry is in charge of creating products which require a high difficult range such as the ability of driving a lift fork in warehouses. Traning forklift drivers might be a risky task when interacting directly with the l forklift car. (Anylogic ,2019).

Therefore by developing this project ,one of its main porpouses is reducing risks by using a virtual forklift simulator it can also help us improve the task of driving a forklift

Background

We count with contributions that use a forklift simulator with the development and the implementation of a virtual forklift simulator to train forklift operators, the study compared traditional training methods with a VR-based training approach, assessing their impact on energy consumption and overall efficiency of forklift operations in airport cargo terminals (Kierzkowski, A, 2024)

In addition several studies have been made that use simulation to optimize automotive assembly lines , highlighting their contribution to improve productivity and cost reduction in automotive industry. The simulation-based optimization is used to find feasible scenarios with least reconfiguration, stochastic, influences such station failures and reactive scheduling decisions can be considered (Rachner et al, 2023)

While some other authors have also been interested in the meta-analysis on the effectiveness of training simulators for crane operators, analyzing the impact on industrial security and skills acquisition by operators, The commercial release of affordable, low-cost, and consumer-ready virtual reality (VR) devices has increased the accessibility for researchers to investigate the benefits of VR technology including those aimed at education and training. VR technology provides several opportunities that may provide benefits over traditional training methods (Song et al, 2021)

Some other projects about safety at work in contruction industry have been made by using Virtual reality simulators , these simulators were able to improve safety an efficiency at work o (Ra chner, 2023)

On the other hand there are also outcomes when using Virtual simulators in the teaching-learning process in the different educational instances showing the need of encouraging and appreciating art and culture .

It is important to find effective ways to promote experiences related to art for students in order to develop multiple learning intelligences , especially focused to spaces and enviroments. Therefore virtual tours are a very important tool to appreciate art from any place in the world; this methodology allow us explore places and spaces in a virtual way an so then people can get knowledge by using cultural resources from different institutions and museums. (Calvillo Villicaña, 2024).

Simulation is used to improve material handling in a factory , showing how this tool can improve efficiency and operational cost reduction (Kim, 2021).

Comparative studies have been made by using different virtual reality simulators used in cranes operators training, assessing effectiveness and impact when training. (Lee, 2019).

The researching group Wang et 2018 made a research analysis that use simulation to analyze automatic guided vehicle systems in warehouses, providing an overview of their application and outcomes as well (Wang, 2018).

Another longitudinal field of study examines the long-term effects of virtual reality training for industrial truck drivers, evaluating its impact on job safety and drivers performance (Rodríguez, 2020).

It was also analyzed a case study about optimizing material flow in automotive manufacturing plants by using simulation, highlighting improvements in efficiency and productivity (Chen, 2019).

The Kim and Park working group describe a experimental report where they obtained research results with a variable focused on effectiveness, in the training of forklift operators through virtual reality simulation, assessing its impact on safety and the acquisition of skills by the operators (Kim, S., Park, J., 2017).

A contribution has been obtained from a study case by implementing a training program based on simulation to provide maintenance to industrial equipment improving times reduction and different virtual reality simulation approaches for assembly line balancing (Jones, 2018).

A simulator that uses ultra broadband technology with UWB measurements from a real sensor array was used as well. This simulator was used also with a localization algorithm and a physical model of a forklift, position estimates were obtained in different scenarios with different obstacles, a UWB was also modeled and simulated as well, an additional inertial sensor and an optical sensor were also modeled to test their effect in supporting UWB-based location (Kierzkowski, Ryczyński, & Kisiel, 2024).

The other authors conducted a study based on collaborative virtual environments (CVE) that offers a promising avenue for inclusive teamwork training. (Amat et al. 2024) An application was found that presents an experimental concept for developing a realistic human-machine interaction (HMI) for a Virtual context (VE) and a new methodology for assessing the system. This assessment is generated to facilitate the transfer of VE model/knowledge to a Real Environment (RE), where the VE is implemented to activate user behavior similar to that of RE. This analyzes the application of that concept to assess forklift interactions operation in the VE. First, a virtual reality forklift simulator is used. The simulator is developed using motion capture and 3D (J. Y. Chew, 2019).

The autor Preutenborbeck (2024), in their article they show the integration of haptic feedback into virtual assembly systems, providing a comprehensive overview of the current state of research, a systematic literature review.

The review is carried out focusing on applications, study designs, haptic devices and the effectiveness of haptic feedback. The review shows that haptic feedback can increase immersion in virtual environments and thus improve the quality of information and highlights the potential of the systems for future virtual assembly applications.

Methodology

A virtual simulator for desktop application format was developed, in 5 phases, these phases were implemented by the team work to develop a design, the modeling of the forklift, the programming of interactions in Unreal Engine software, the implementation of interactions, verifying the logic of movements and testing on desktop computers and with operators.

Phase 1: Environment Design

The design was made by using Blender software, with this software the physical facilities of the factory were designed where the forklift is located and working. In order to develop this phase of the project a basic model of a warehouse and a fork lift obtained from the store Epic Games, it allowed us to start from zero at the environment design phase.

Once the warehouse was composed and visualized, a search was carried out on the Internet for some models of objects that could be added to the warehouse, such as: containers, shelves, pallets, etc. Some of the sites that were useful for downloading models are:

<https://free3d.com/es/modelos-3d/de-madera>

<https://www.turbosquid.com/es/>

<https://sketchfab.com/tags/modelos>

Creating realistic 3D models of facilities, machines, halls, and obstacles found within the facilities.

Objects were selected, after they were modified in Blender and in the cases necessary for the warehouse. Likewise, the design of the lights, obstacles, platforms, walls, and windows, and they were integrated into the design of the warehouse.

It was necessary to have a general idea of how the warehouse was built, hence a research was made about industrial warehouses in order to have a first generic draft.

On Figure 1 it is shown the Desktop application for p.c. of the Desktop Forklift Simulator DFS, that allows to access the application

Box 1

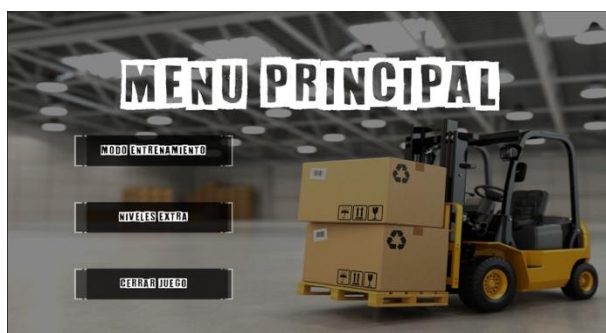


Figure 1

Main menu Desktop Forklift Simulator -DFS.

Source: Own elaboration

Phase 2: Modeling the forklift

Redesigning the forklift 3D model in Blender. Making sure to include details such as the cabin of the driver, forks, wheels, lights, levers, steering wheels, pedals, mirrors and any other necessary components.

Figure 2 shows the design of the forklift integrated with environment objects.

Box 2



Figure 2

Design screen showing the forklift integrated with environment objects

Source: Own elaboration

Figure 3 shows the forklift in a virtual environment with objects and lights that allow realistic interaction.

Box 3



Figure 3

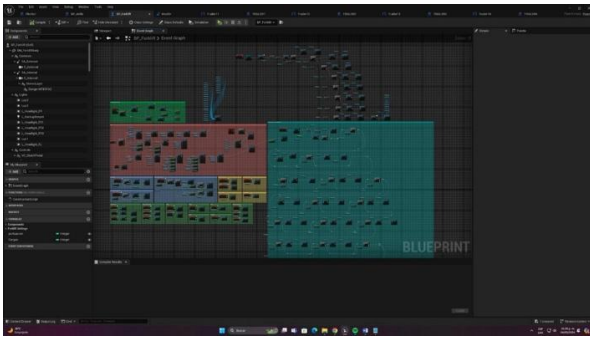
Screenshot with lights in the warehouse and the forklift

Source: Own elaboration

Phase 3 Programming in Unreal Engine

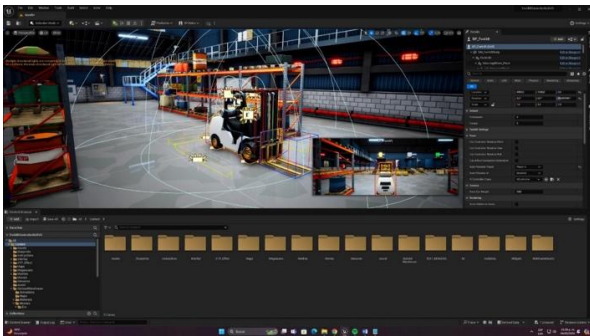
A new project is created in Unreal Engine and the virtual reality settings are set up according to the device specifications. The 3D models and animations created in Blender are imported into the Unreal Engine project.

The game logic is then developed to control movements and interactions of the current forklift and the warehouse using Blueprints, these blueprints can be created from the ground or can be imported from other sources, as can be seen in Figure 4 and Figure 5.

Box 4**Figure 4**

Screenshot showing Blue prints used to create physics , movements and animations for the forklift , and the necessary enviroment

Source: Own elaboration

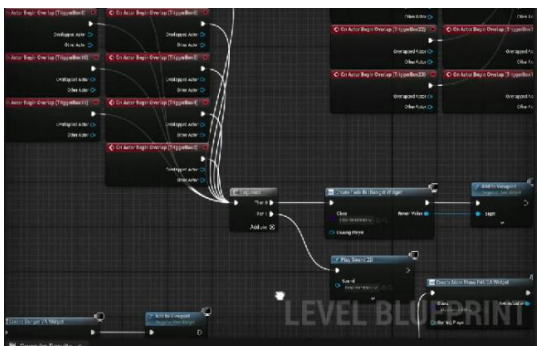
Box 5**Figure 5**

Screenshot showing the DFS in operation

Source: Own elaboration

Phase 4: Implementing interactions

Figure 6 shows how the logic implementation is performed so that the forklift can interact with objects in the environment, such as picking up and dropping pallets, avoiding collisions, etc.

Box 6**Figure 6**

Screenshot showing visual programming by using blue prints used by the forklift to interact with the virtual enviroment

Source: Own elaboration

Box 7**Figure 7**

Screen shot from the warehouse for the DFS

Source: Own elaboration

Figure 7 shows the industrial warehouse environment verifying that interactions are realistic but also respond appropriately to the actions of the player who is known in the game as the operator.

Phase 5: Testing and Optimization

Verification of different simulator movements to identify but also solve errors or performance problems. It is verified that the support software updates are implemented, this is for the maintenance of the simulator, which allows it to maintain good performance.

During the development process of the simulator, different tests were carried out, both by the members of the development team and by the higher education institution as well as by a manufacturing company which helped a lot with feedbacks.

Box 8**Figure 8**

Tests carried by operational staff of a manufacturing company installed in San Juan del Río, Qro.

Source: Own elaboration

Figure 8 shows one of some visits of operational personnel to the University where the software was developed and at this stage feedbacks of the simulator were obtained, where it was verified by the operators that the experience is perceived as a very realistic for handling and somewhat revolutionary in virtual learning about real actions.

It is also important to mention that a comparison was made with the course that was received to simulator developers by the manufacturing, where real experience of driving and using a real forklift in the factory was obtained, where it was perceived that the vision and the teaching method taught in the virtual simulator are similar, and therefore it provides many benefits, such as that the operator candidate starts with more confidence and security, the ease of adaptation and the faster learning process, as can be seen in figure 9, the software developers handling forklifts in the maneuvering yard.

Box 9



Figure 9

A member of the team developers using a real forklift to obtain real experiences to take them to a programming environment

Source: Own elaboration

Results

From the variables analyzed to verify the outcomes of the implementation of a virtual forklift simulator, a satisfaction level survey was designed and prepared, where the outcomes are presented in graph 1. A graph where the weighting is from 0 to 10, identifying the level of effectiveness of each essential aspect of the simulator, as it can be seen the level of realism and effectiveness of the simulator is acceptable. The universe is made up of 10 forklift operators from a company.

The forklift operators used the application in order to make an evaluation of the 7 variables that were chosen, which are: 1. Accessibility 2. Satisfaction 3. Playability 4. Realism 5. Sound 6. Reaction 7. Environment.

Box 10

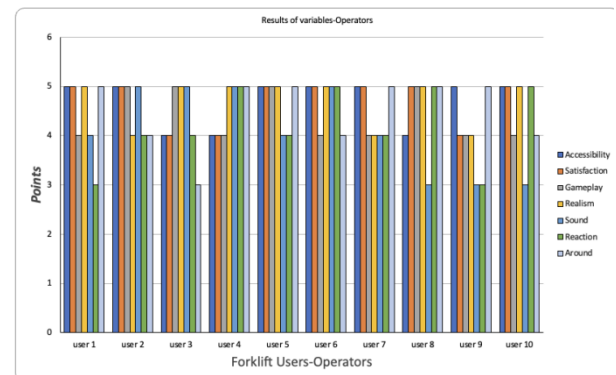


Figure 10

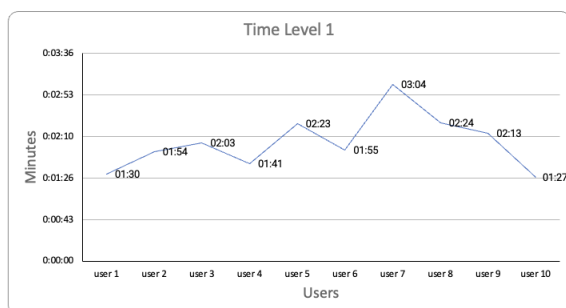
Graphic results showing assessments from forklift operators considering the 7 variables

Source: Own elaboration

Figure 10 shows the outcome of the lowest score obtained by forklift operators, which was 3/5; the highest score obtained was 5/5, in which 50% of users rated at least one variable with 3; 100% of users rated at least one variable with 5. While ratings obtained from the variables: the maximum rating is 5 and the minimum 0.

Ratings are obtained with the arithmetic mean, for example "Accessibility" has 4.7 since 7 users assigned 5 points $7 * 5 = 35$; 3 users assigned 4 points $3 * 4 = 12$ total points obtained $35 + 12 = 47$ Dividing the total points between the 10 users $47/10 = 4.7$; Accessibility rating 4.7; Satisfaction rating 4.7; Playability rating 4.4; Realism rating 4.7; Sound rating 4.1; Reaction rating 3.8; Environment rating 4.5.

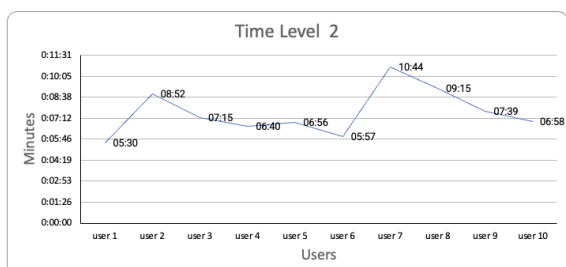
As it can be observed 7 out of 10 users rated accessibility, satisfaction and realism with a maximum score; likewise, 7 out of 10 users assigned at least 4 variables with a maximum score.

Box 11**Figure 11**

Graphic results of time used for level 1

Source: Own elaboration

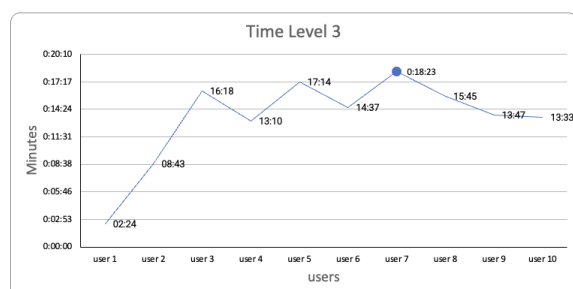
Figure 11 shows the outcomes of the times when using the software in the time taken to interact and get into level 1. Arithmetic mean \bar{X} : 02:03 minutes; Minimum time: 01:27 minutes; Maximum time: 03:34 minutes, with a difference of 01:31 minutes.score.

Box 12**Figure 12**

Graphic outcomes to show time used to get into level 2

Source: Own elaboration

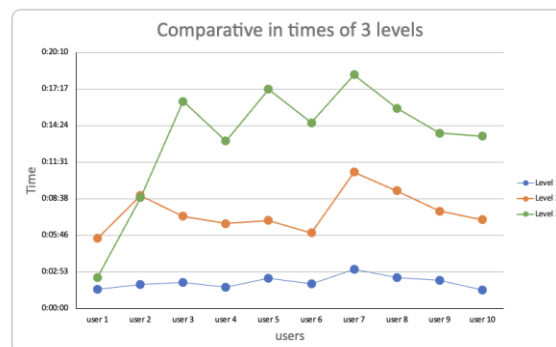
Figure 12 shows the outcome for level 2, the following times were achieved: Arithmetic mean \bar{X} : 07:35 minutes; Minimum time: 05:30 minutes; Maximum time: 10:44 minutes.

Box 13**Figure 13**

Graphic results of time used for level 3

Source: Own elaboration

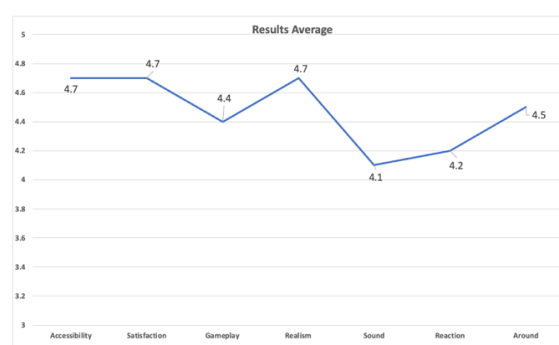
Figure 13 showing the outcome for level 3; For level 3 the following times were achieved: Arithmetic mean \bar{X} : 13:23 minutes; Minimum time: 18:23 minutes; Maximum time: 02:24 minutes.

Box 14**Figure 14**

Graphic outcomes showing the comparison of time at the 3 levels of play

Source: Own elaboration

Figure 14 shows the time taken for each level of play, where the longest time is found at level 3 with a duration of 17:17 minutes and the shortest time at level 3 is 02:53 minutes, user 1 was the one who generated the shortest time at his level and user 7 was the one who had the longest time, this is because of the experience of using video games.

Box 15**Figure 15**

Graphic outcomes showing averages with variables evaluated by forklift operators

Source: Own elaboration

Figure 15 shows how all variables that were evaluated when using the forklift operations behave, where the average of satisfaction and realism had the highest average 4.7, by the operators, which indicates that for them the use of the software is satisfactory and very realistic allowing them to advance in their interaction and knowledge of handling when interacting with the software, while the sound with an average of 4.1 and the reaction with 4.2, were the lowest evaluated, this indicates that even when the software is in a virtual environment, there was still a complication to react in locating objects, and the sound was not efficient since a good audio message was not perceived.

Conclusions

By developing the software program for a desktop application format, it allowed to work with visual programming and block design through objects that were first tested individually, and then integrated into a industrial warehouse, all together with the virtual forklift, this allowed to have a virtual environment, to be used by the forklift operators that collaborated with the software developers, in which operators showed that a training strategy through technology is very supportive, and with the virtual environment, this indicates that this type of applications will be necessary mainly for the manufacturing industry, which is a support for their training, it is also an aid to reduce accidents and fuel costs, with this type of specialized software it is recognized that the benefit is of high impact for companies where forklifts are used.

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Authors' Contribution

The contribution of each researcher in each of the points developed in this research, was defined based on:

Juárez Santiago Brenda: Contributed to the project idea, research method and technique and background. She carried out the data analysis and systematization of results, as well as writing the article.

Mendoza Hernandez Guillermo: Contributed to the project idea, research method and technique. She carried out the data analysis and systematization of results, as well as writing the article.

Ledesma Uribe Norma Alejandra: contributed to the research design, the type of research, the approach, the method and the writing of the article.

Santos Osorio Rene: worked on the application of the field instrument, data collection and systematization of the results. He also worked on the writing of the paper.

Availability of data and materials

In order to create de 3d models the team used Unreal Engine. version 5.1 and. Blender Version 3.x free software and for image editing. the team used the software Photos installed. By default within the operating system Windows 11.

Funding

The economic resources for developing the simulator were obtained from SEDESU (Secretaria de desarrollo. sustentable) in Querétaro State within a government program called PEDETI (Programa Estatal para el Desarrollo de Tecnología e Innovación), the resources allowed us to get computers, pedals, wheels. levers and cars for videogames.

Abbreviations

DFS	Desktop Forklift Simulator
RE	Real Environment
VE	Virtual Context
VR	Virtual Reality
HMI	Human-Machine Interaction
UWB	Ultra-Wideband

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Speed control of 3 phase induction motor using an RC circuit as a start signal

Control de velocidad de un motor trifásico de inducción usando un circuito RC como señal de arranque

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CONAHCYT classification:

Area: Social Sciences
 Field: Business and administration
 Discipline: Administration and management
 Sub-discipline: Business administration

<https://doi.org/10.35429/JOTI.2024.8.21.1.8>

Article History:

Received: January 30, 2024

Accepted: December 31, 2024

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Abstract

Overcoming Resistance of the initial condition in three-phase electric motors is essential in applications where it's had high initial consumption demand, such as HVAC Systems, pumps or compressors, higher torque ensures reliable operation even under varying conditions of load. These motors can provide efficient operation for heavy loads or when starting under load conditions. In this work an RC circuit is used for starting signal of a 3-phase induction motor, advantages of using an RC circuit against a conventional variable frequency controller are shown in the article

Resumen

Superar los valores resistivos en la condición inicial de los motores eléctricos trifásicos es esencial en aplicaciones donde necesitan una alta demanda de consumo inicial, como sistemas HVAC, bombas o compresores, un par más alto garantiza un funcionamiento confiable incluso en condiciones variables de carga. Estos motores pueden proporcionar un funcionamiento eficiente para cargas pesadas o al arrancar en condiciones de carga. En este trabajo se utiliza un circuito RC para la señal de arranque de un motor de inducción trifásico, en el artículo se muestran las ventajas de utilizar un circuito RC frente a un controlador de frecuencia variable convencional.

Goal

- Relationship between RPM and torque
- RC auxiliary signal
- Controller of VFD
- Measurement

$$V_c = K_v \left(1 - e^{-\frac{t}{\tau}} \right)$$

Contributions: The design process of an auxiliary signal controller for a VFD.

Methodology

Design

Acquisition

Processing & Results

Objetivos

- Relación entre RPM y torque
- Señal auxiliar RC
- Medición del controlador de VFD

$$V_c = K_v \left(1 - e^{-\frac{t}{\tau}} \right)$$

Contribuciones: El proceso de diseño de un controlador de señal auxiliar para un VFD.

Metodología

Diseño

Adquisición de datos

Procesamiento y resultados

Torque, Circuito Aplicaciones

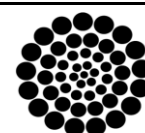
Torque, Circuito Aplicaciones

Citation: Juárez-Toledo, Carlos, Martínez-Carrillo, Irma, Hernández-Epigmenio, Miguel Ángel and Camacho-Altamirano, Ulices. [2024]. Speed control of 3 phase induction motor using an RC circuit as a start signal. Journal of Technical Invention. 8[21]-1-8: e40821108.



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Introduction

Detailed examination of motor starters, advances in torque control algorithms and the evolution of electric motor controllers emphasize the importance of integrating sophisticated technologies for efficient and reliable operation of motors.

Since the start of the design and development of AC motors, classical theories have emphasized the significance of effective control for electric motors in industrial environments, which heavily depends on the utilization of electric motor starters (Anderson J., 1922). Another example is the use of electric motors in large-scale farm irrigation systems, which are powered by a single-phase grid supplemented by solar photovoltaic energy and battery storage. The system employs TS-fuzzy based direct torque control to enhance robustness during load variations (Sareddy, et al., 2024). Also, it is essential to meticulously examine the components of these starters and carefully select the principles governing their operation. However, this involves exploring the array of starter types available and carefully assessing their applicability across diverse contexts. Such thorough scrutiny is paramount to ensuring the seamless functionality of electrical systems.

Many studies have examined the potential for generalizing speed algorithms of starting and integrating them into a comprehensive. (Abbas, et al., 2024). Nevertheless, in the control of adjustable speed drives, the reliable performance of inexpensive digital integrated circuits is nearing a point where traditional control procedures may be supplanted by novel algorithms and methods that better leverage their speed and functional capabilities. (Ilic-Spong, et al., 1987).

Several recent papers have explored sophisticated technologies concerning to design of electric motor drives, examining their evolution in structure, converters, heat dissipation, volume optimization, and electromagnetic interference. (Zhang B, et al., 2022) and (Bolognani S, et al., 2009).

In numerous industrial and commercial scenarios, the initial surge experienced by electric motors, particularly those operating on three-phase systems, however, presents significant hurdles due to its detrimental impact on both power grids and equipment. Start the electric motor study delves into the electrical traits and practical advantages associated with optimizing electric motor startups, shedding light on its efficacy in reducing strain on electrical systems and enhancing overall performance. (Hardine Linkha, et al., 2022).

Variable Frequency Drives (VFD) have become an essential technology for controlling electric motors; Many studies explore the benefits of VFDs, their main advantages include energy savings, better process control and longer equipment life. Synthesizes recent scientific research findings to provide a comprehensive overview of the importance of VFDs. (Almeida, et al., 2005)

VFDs enhance process control by allowing precise adjustments to motor speed, leading to improved product quality of the manufacture. This is particularly important in applications requiring specific speed profiles or frequent speed changes. Nevertheless, each innovative electrical apparatus for industrial applications must be thoroughly tested, both during the development process and for compliance testing. The development of a new electrical system should be accompanied by the parallel design of a customized measurement system, with performance specifications tailored to the features of the system under test. (Fiorucci, et al., 2013)

Most motors are designed to operate at a constant speed and provide a constant output; however, modern technology necessitates variable speeds in many applications where electric motors are used. This growing interest has led to extensive research and development aimed at optimizing VFD performance and integrating them more effectively into various industrial processes. Consequently, understanding the energy-saving potential and economic benefits of VFDs has become a critical focus (Saidur, et al., 2012).

Variable frequency drives have significantly influenced the improvement of global energy consumption. Accordingly, the widespread adoption of variable frequency drives (VFDs) to replace traditional non-adjustable or single-speed variable frequency drive systems could result in significant energy savings globally. For applications that demand high-performance VFDs and precise speed control, ensuring accurate rotor speed information is essential, so installing a reliable speed sensor is necessary. (Ibrahim M. et al., 2013).

Complementary studies could include research where the AMB study enhances rotor speed and stability using a dual-loop control mechanism, while the VFD study optimizes starting torque and energy efficiency in AC motors through the use of auxiliary signals and advanced control algorithms. Both studies share a common focus on improving control and efficiency in motor systems (Pachau, J., et al., 2023).

In certain industrial applications, it is necessary to start motors with heavy loads, requiring speed control to initiate these systems. However, this presents a challenge because these motors typically start at with linear speed increment. The primary focus of this paper is to provide an account of the design process of an auxiliary signal controller for a VFD. This paper reviews the current state, and trends of measurement techniques and instruments applied for the experimental characterization of variable speed drives using Resistive-Capacitive (RC) Circuit signal for starting condition.

Methodology

The methodology of this paper combines theoretical model of RC circuit with practical analysis to explore the advantages of using RC signal to start three-phase induction motors, providing comprehensive information on how to improve motor starting performance.

Circuit RC

Resistive-Capacitive (RC) circuit is a fundamental component in electrical engineering, The circuit is widely used because it is possible to predict its state behaviour.

The RC Circuit serving critical roles in various applications such as filtering, timing, and signal processing. (Grigorescu et al., 2008). Some studies introduce and analyse innovative applications using the RC circuit as a source of information generation, demonstrating its great reliability for their application. (Hidalgo., 2023).

An RC circuit's primary function is determined by the relationship between resistance (R) and capacitance (C). When a voltage is applied, the capacitor charges or discharges through the resistor, governed by the time constant τ (tau), defined as

$$\tau = RC \quad [1]$$

This time constant determines the rate at which the capacitor charges or discharges, influencing the circuit's behavior in filtering and timing applications.

Box 1

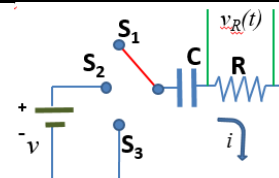


Figure 1
RC Circuit

Source: Own elaboration

The RC circuit in Figure 1 consists of a voltage that charges a capacitor, and a resistor has been connected in series with the capacitor to make the charge/discharge process slower. The switch has three positions (see table 1):

Box 2

Table 1

Capacitor Status

Switch status	Capacitor Status
S ₁	initially downloaded
S ₂	Loading via R
S ₃	downloading via R

Source: Own elaboration

To find the dynamic behavior of the system in the resistance i.e. ($v_R(t)$) with the switch in positions S₂ and S₃.

As can be seen in figure 1, if the switch changes to S_2 , the voltage across the resistor v_R varies in time and the source voltage is divided into voltage of the capacitor and the voltage of the resistance. Using the voltage relationship, the differential equation that describes the behavior of the simple mesh is

$$v = \frac{1}{C} \int i dt + Ri \quad [2]$$

If the current is known, we can directly determine the voltage. Using the change to the Laplace domain we can rewrite the equation in the following form.

$$v = \frac{I_s}{CS} + R I_s \quad [3]$$

By factoring I_s and ordering we can determine the following transfer function

$$\frac{I_s}{V_s} = \left(\frac{C S}{R C S + 1} \right) \quad [4]$$

To determine the current i over time it is necessary to apply the Laplace inverse, as shown below.

$$i(t) = \frac{K_v}{R} e^{\left(\frac{-t}{\tau}\right)} \quad [5]$$

Where K_v represents the constant source magnitude in volts. Finally, the voltages are:

$$\begin{cases} V_R = K_v e^{\left(\frac{-t}{\tau}\right)} \\ V_C = K_v \left(1 - e^{\left(\frac{-t}{\tau}\right)}\right) \end{cases} \quad [6]$$

Case Study

To carry out the work, a Siemens brand frequency converter was used due to the easy adaptation of the proposed methodology.

A $47 \text{ k}\Omega$ resistor and a $330 \text{ }\mu\text{F}$ capacitor are used to create the motor start signal (see figure 2). The voltage of alimentation of the start signal circuit is 9.5 v.

The principal characteristics of the induction motor are: Rated power 0.246 KW, Rated voltage 220 v, Rated current 0.9 A, Rated Speed 2840 RPM, Efficiency 0.66 and Frequency 60Hz. Figure 2 shows the components used.

Box 3

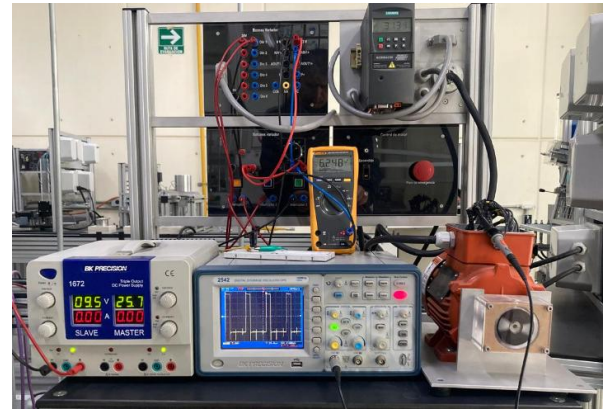


Figure 2

Measuring equipment used in the laboratory

Source: Own elaboration

Results

Solution is presented in three ways:

- **VFD:** corresponds to the measurement curve generated directly by the frequency converter without any external signal, i.e. they are the linear outputs of conventional VFDs.
- **RCC:** It is the measurement response obtained by incorporating RC circuit as an auxiliary signal to start the motor.
- **SIM:** For the signal corresponding to the voltage values resulting from the use of the simulator in Figure 3, it was obtained from equation (6). MATLAB was used for floating point interpolation to simulate the frequency and speed responses for Figures 3 and 4 respectively.

Box 4

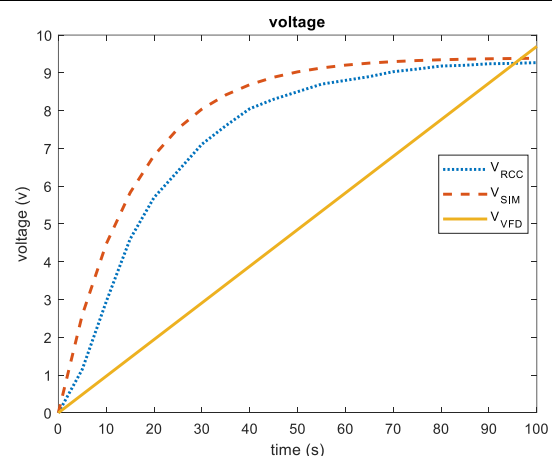


Figure 3

Voltage response

Source: Own elaboration

Using a simple MATLAB floating point interpolation routine, we can get the following result for simulation frequency and speed Simulation of figures (4 & 5), while the V_{SIM} voltage of simulation in figure 3 is obtained using equation 6.

Box 5

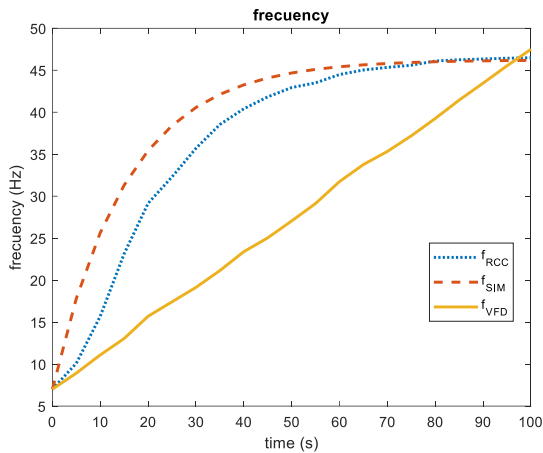


Figure 4

Frequency response

Source: Own elaboration

Numerous studies have concentrated on enhancing power electronics technology, and advancements in semiconductor electronic devices have increased reliability and reduced costs. This progress has led to the development of modern solid-state of the VFD. VFDs are electronic devices that control the speed of induction motors by varying the frequency, offering increased efficiency, reliability, and low maintenance costs. However, they still utilize linear signals for motor starts. (Enemuoh, et al., 2013).

Box 6

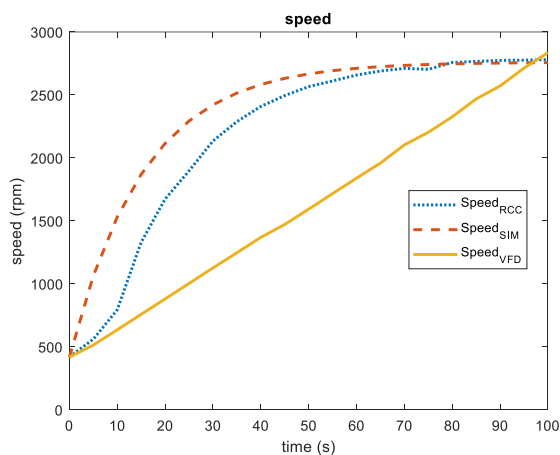


Figure 5

Speed response

Source: Own elaboration

It is evident that the voltage, frequency, and speed outputs of conventional VFDs are linear, which is not optimal for generating sufficient starting torque when the motor is under extreme load. The variations in voltage, frequency, and speed for conventional VFDs are illustrated in the figures 3-5.

When an auxiliary voltage signal is incorporated into the analog input of the frequency converter, the original linear signal from the VFD is changed to a signal with a higher speed at first. This is desirable when the motor is under stress and needs a higher torque to break the moment of inertia.

Box 7

Table 2

Frequency of five times constants τ

time constant	Time (s)	F. VFD (Hz)	F. RCC (Hz)
τ_1	15.51	13.0500	23.1500
τ_2	31.02	19.1400	35.7000
τ_3	46.53	25.0400	41.8300
τ_4	62.04	31.7400	44.4900
τ_5	77.55	35.3300	45.3400

Source Own elaboration

Table 2 shows that the frequency obtained in the laboratory using an RC circuit is higher than the conventional VFD system for the five τ values [τ_1, \dots, τ_5].

The ideal electric motor drive for traction applications in electric vehicles should deliver high torque at low speeds for acceleration and demanding conditions, and low torque at high speeds for regular driving (Ehsani M, et al., 2003).

The relationship between engine power, speed (RPM) and torque is fundamental in the design of electric motors. The instantaneous torque of an angular speed is the power times the angular velocity. Future work will aim to clarify these interrelated concepts and their practical implications. The relationship between frequency and Pulse Width Modulation (PWM) in induced electric motors is fundamentally connected to the concept of speed. The figure 7 below illustrates speeds for different frequency values, corresponding to time τ_1 of Table 2.

VFDs are amply used in industrial applications because they provide an efficient means of varying the speed and torque of three-phase motors. A VFD utilizes a diode bridge to convert AC voltage to DC, and then reconverts it from DC to AC at a specific frequency used to control the motor's speed. Figure 7 shows the variation in the period of voltage pulses. The data of figure 7 are directly obtained using an oscilloscope by selecting the three different frequency values of time τ_1 (15.51s) on the Siemens frequency converter.

Box 8

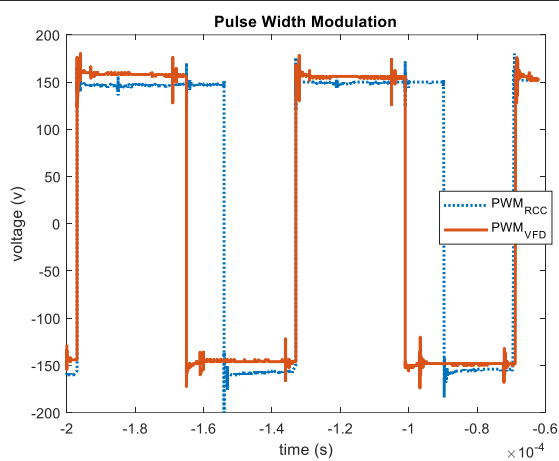


Figure 7

Pulse Width Modulation of time τ_1

Source: Own elaboration

Figure 7 shows the variation in the voltage pulse widths, where the most significant was the pulse width for 23.115 Hz corresponding to the RCC signal, and the smallest was for 13.05 Hz corresponding to the conventional VFD, this method provides a reliable way to adjust the frequency of the three-phase motor to vary the speed.

Conclusions

The use of VFDs has demonstrated benefits for AC motors, including energy savings, enhanced industrial process control, and extended equipment life. However, conventional VFDs typically provide limited, linear starting torque, which is inadequate for motors under excessive starting load conditions.

Advancements in speed control of AC electric motors have necessitated novel improvements in motor starters, including the integration of torque control algorithms, reflecting the evolution of AC motor controllers.

Accordingly, our analysis examines the incorporation of a start signal into a commercial VFD to improve the efficiency and reliability of AC motors, particularly in scenarios where they face high initial starting torque.

The experimental results presented in this paper confirm the effectiveness of using an RC circuit as an auxiliary power signal for VFDs, demonstrating higher starting power and torque under heavy loads. This notwithstanding, this methodological approach leverages the predictability and reliability of RC circuits, presenting a promising direction for future enhancements in AC motor starting control technology.

The paper emphasizes the importance of understanding the relationship between PWM and speed in motor design, particularly for applications requiring high torque at low speeds. Future research will focus on further clarifying these interrelated concepts and their practical implications.

This research focuses on more advanced starting torque solutions that can better protect motors under initial load conditions using a RCC auxiliary signal. Accordingly, the application of more aggressive auxiliary signals, such as antilogarithmic signal through an instrumentation op-amp, can produce an output frequency response antilogarithm. These techniques are currently used in analog computing and signal processing and will be explored in future research.

The implementation of artificial intelligence introduces new possibilities for addressing complex problems (Guedes 2024). Looking ahead, the integration of neural networks is anticipated to facilitate more precise control mechanisms.

Declarations

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Author contribution

The contribution of each researcher in each of the points developed in this research, was defined based on:

Juárez Toledo Carlos: Contributed to the project idea, method, and research technique. Conducted data analysis and systematization of results.

Carrillo-Martinez, Irma: Provided advice on systematization and background for the state of the art and development of the proposed method. Supported the design of the mathematical model.

Hernández-Epigmenio, Miguel Angel: Assisted with data analysis and systematization of results and wrote the article.

Camacho-Altamirano, Ulices: Worked on the application of the field instrument, data collection, and systematization of results.

Availability of data and materials

The data were collected and analyzed in the automation laboratory at the Autonomous University of the State of Mexico.

Funding

The research did not receive any funding.

Acknowledgements

Master's degree in automotive electrification from UAEMex for providing valuable ideas to the development of the project.

Abbreviations

AC	Alternating Current
VFD	Variable Frequency Drives
SIM	Simulator Response
τ	tau
RCC	Resistive-Capacitive Circuit
PWM	Pulse With Modulation
op-amp	operational amplifier

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Vivaldi antenna design and simulation with Bakelite substrate compared to RT duroid 5880 substrate


Diseño y simulación de antena vivaldi con sustrato de baquelita comparado con sustrato RT duroid 5880

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CONAHCYT classification:

Area: Engineering

Field: Technological sciences

Discipline: Telecommunications technology

Subdiscipline: Antennas

 <https://doi.org/10.35429/JOTI.2024.8.21.5.6>

Article History:

Received: January 30, 2024

Accepted: December 31, 2024

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Abstract

The main objective of this paper is to show the difference between two vivaldi antennas simulated with two different substrates, the first one is bakelite, since it is very easy to find a phenolic plate for the simplest electronics projects, this type of plate consists of one or two copper plates on the outside and a bakelite plate that separates them. However, the intention of the article is to compare this type of material so commercial with a material that has gradually made its way into the field of communications in a wide bandwidth, called RT duroid 5880 from Rogers Corporation and show the differences in relation to the gain. It is worth mentioning that this work shows the development of the antenna design using simulation software and that the development of this antenna will be adapted to contribute to later projects.

Objectives	Methodology	Contribution
The main objective is to show the difference between simulated vivaldi antennas with two different substrates: bakelite and the RT duroid 5880	The methodology includes the use of High Frequency Simulation Software (HFSS) belonging to Ansys.	The contribution shows a clear development of new construction elements of telecommunications devices.

Resumen

El objetivo principal del presente trabajo es mostrar la diferencia entre dos antenas vivaldi simuladas con dos diferentes sustratos, el primero es la bakelita, ya que es muy fácil encontrar una placa fenólica para los proyectos más simples de electrónica, este tipo de placa se conforma de una o dos placas de cobre en el exterior y una placa de bakelita que las separa, sin embargo, la intención del artículo es comparar este tipo de material tan comercial con un material que poco a poco se ha abierto camino en el campo de las comunicaciones en un ancho de banda amplio, llamado RT duroid 5880 de la empresa Rogers Corporation y mostrar las diferencias en relación a la ganancia. Cabe mencionar que este trabajo muestra el desarrollo del diseño de las antenas utilizando software de simulación y que el desarrollo de esta antena se irá adaptando para contribuir a proyectos posteriores.

Objetivo	Metodología	Contribución
El objetivo principal del presente trabajo es mostrar la diferencia entre antenas vivaldi simuladas con dos diferentes sustratos: bakelita y el RT duroid 5880	La metodología incluye el uso de software High Frequency Simulation Software (HFSS) perteneciente a Ansys.	La contribución muestra un claro desarrollo de nuevos elementos de construcción de dispositivos de telecomunicaciones.

Antenna, Vivaldi, Duroid 5880

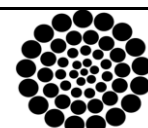
Antena, Vivaldi, Duroid 5880

Citation: Cruz-Orduña, María Inés, Ramos-González, Luz María, Benavides-Cruz, Alberto Manuel and Calderón-Sánchez, Javier. [2024]. Vivaldi antenna design and simulation with Bakelite substrate compared to RT duroid 5880 substrate. Journal of Technical Invention. 8[21]-1-6: e10821106.



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Introduction

The development of this research work is framed with the research projects that arise from academic bodies in which the participants of this article are integrated. It is very common in the area of electronics design to be able to use inexpensive instruments for the exercises and main topics of instrument design, such as phenolic plates that are used from the first semesters of the study of electronics to design electrical and electronic circuits and whose cost does not exceed twenty pesos (on a single-sided plate of 10 cm by 10 cm) [1] however, With FORME, the topics of the area are being specialized, different materials are being used not only as conductors but also for the development of more specific devices.

This type of phenolic plate that is mentioned in the previous paragraph has the main characteristic that its faces are made of copper (in the case of when it has both metal faces), since copper is the metal also most used by electrical and electronic devices due to its conductive properties, however, the subject of study of this article is Bakelite, The material that has the plate in the central part, since it is known that this material was the first plastic that was chemically synthesized, from 1907 to date it has been on the market [2] covering the necessary requirements of design and implementation in various electronic devices.

Over the years, electrical and electronic systems evolved to make improvements in life, for example, in the area of health it is very common to find different devices that serve as support to the medical staff to be able to clearly determine the condition of a patient, proof of this is shown in the article "the crucial importance of imaging in the diagnosis of cranial pathology" [3] where they make use of of different imaging techniques for the diagnosis of cranial pathologies such as radiography, ultrasound and scintigraphy, among others. We also use technology for media that are advancing by leaps and bounds, a clear example is the issue of the implementation of technology in education, as shown in the article "Evolution of Information and Communication Technologies in Education" [4] where it shows a clear comparison of the use of technologies in education from the 1970s to 2022, giving a guideline to the entry of social networks and even emphasizing the rise of artificial intelligence.

In the area of telecommunications, specifically in the area of antennas, there have also been different advances, each time the devices need less space or size, but greater advantages over the previous ones, wide bandwidth, adaptability to the operating systems and the requirements of the system for which they are designed, to mention a few cases. That is why this publication makes the comparison between two types of materials: the oldest and most commercial against one of the new ones on the market. In general, this article will address the design of the antenna with the two substrates separately within the Ansys HFSS simulator, then the results obtained will be shown and these will be discussed in its conclusions.

RT duroid 5880 in recent applications

In the article Development of Rogers RT/Duroid 5880 Substrate-Based MIMO Antenna Array for Automotive Radar Applications, the design of a patch antenna for the new smart cars is developed, using relatively low frequencies and relying on short-range radars, it is selected because it has a low Constant dielectric and low dielectric loss, making them suitable for high-frequency/broadband applications. [5] In the article Half mode rogers RT duroid 5880 substrate integrated waveguide cavity backed V-slot antenna for C-band applications it is mentioned that a patch antenna is used for applications in the C-band, it mentions that the antenna is designed using a Rogers RT Duroid 5880 substrate with permittivity $\epsilon_r = 2.2$ and its thickness is $h = 0.787$ mm. The RT/duroid 5880 substrate has a low dielectric constant and low dielectric loss, making them suitable for wideband/high-frequency applications. [6].

In the article New Multiband E-Shape Microstrip Patch Antenna on RT DUROID 5880 Substrate and RO4003 Substrate for Pervasive Wireless Communication the use of RT duroid 5880 due to Rogers-Corp's RT DUROID 5880 Substrate is mentioned and compared with RO4003 with dielectric constant of 2.2 and tangent of loss of 0.004. In fact, the articles Gain improvement and return loss reduction of microstrip patch antenna at 12 GHz using rogers RT/Duroid (TM) substrate in comparison with FR-4 epoxy substrate [7].

Analysis of Equivalent Antennas in RT Duroid 5880 and 5870 for GPS Operating Frequency [8] and Gain enhancement of rectangular microstrip patch antenna using Rt-Duroid 5880 substrate and comparison with Rogers 4350 substrate on S-band [9] make a very complete comparison of recent use of the RT duroid 5880 material compared to other materials.

Methodology

The methodology is not very complex because the intention of the article is to present the results of the simulation of the antennas. In support of this methodology, the following diagram (Figure 1) was established in which the development of the methodology is shown step by step as well as the scope of the article.

Box 1

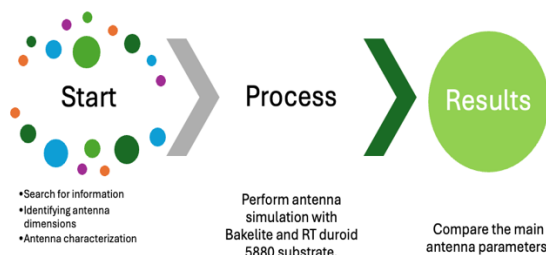


Figure 1

Methodology

Source: Own elaboration

The idea of the work is to be able to bring people closer to the use of the software, which is why each of the windows that arise when the characterization and simulation of the antenna is carried out is developed step by step. Nowadays, this type of description is important for the correct use of specialized software that allows the development of new technologies.

Vivaldi antenna design with Bakelite and RT duroid 5880 substrate

As specified in previous sections, this work is based on the simulation of antennas using Ansys' High Frequency Simulation Software (HFSS), which is one of the most complete software for the development of antennas and electromagnetic field for different frequencies. [10] It is worth mentioning that the vivaldi antenna has an exponential aperture, in addition to the following features:

- 0.035 mm thick copper top and bottom.
- 1.57 mm Bakelite core.
- Antenna Dimensions: 14mm by 19.5mm.
- Initial antenna aperture width of 0.12 mm.

Figure 2 shows the front side of the antenna while Figure 3 shows the back side.

Box 2

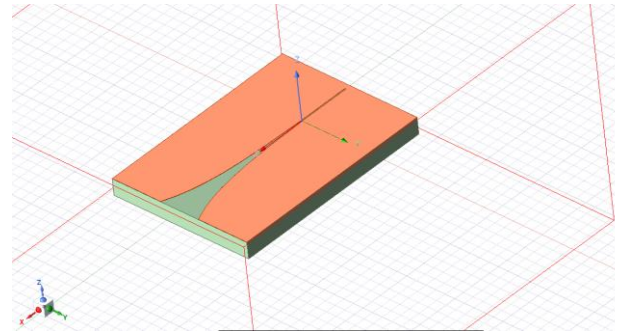


Figure 2

Front face of the antenna

Source: Own elaboration in the Ansys HFSS software

Box 3

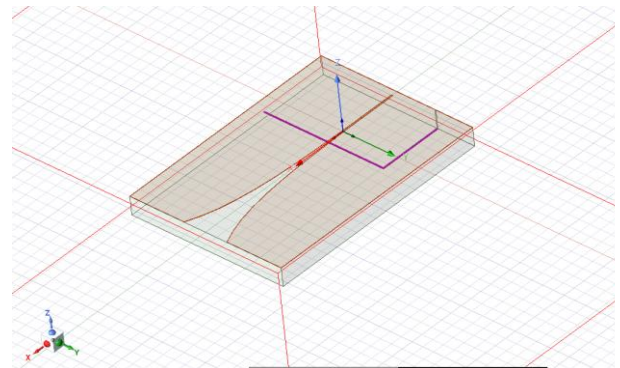


Figure 3

Back of the antenna

Source: Own elaboration in the Ansys HFSS software

These conditions follow the classical theories of Vivaldi antennas, where it is mentioned that for aperture lengths less than half the wavelength (λ), the wave is guided by the groove while for longer lengths, the wave propagates through the dielectric until it is radiated to the outside [11] [12] in the case of the design of this antenna it is worth mentioning that it seeks to develop the simulation at different frequencies of operation, mainly at 10 GHz, which corresponds to a wavelength of 30 millimeters, according to equation 1.

$$\lambda = \frac{c}{f_0} = \frac{3 \times 10^8 \text{ m/s}}{10 \times 10^9 \text{ Hz}} = 3 \times 10^{-2} \text{ m} = 30 \text{ mm} \quad (1)$$

Where λ is the wavelength, c is the speed of light in a vacuum, and f_0 is the operating frequency. To get started, the software environment is shown in Figure 4.

Box 4

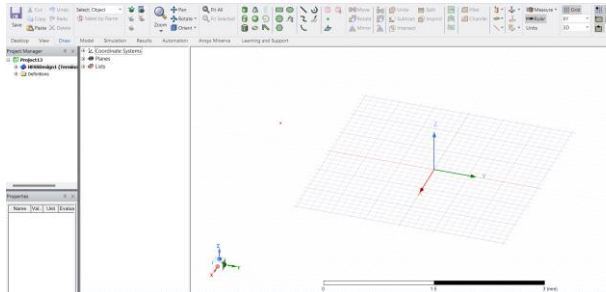


Figure 4

Software Environment

Source: Own elaboration in the Ansys HFSS software

At the top you can see the main icons for the design, this can be manually or by equation. In the case of using the equation shown in figure 5 in the icon marked with a red circumference in the "draw" tab, a window will automatically be displayed to write the equation of the surface you want to use.

Box 5

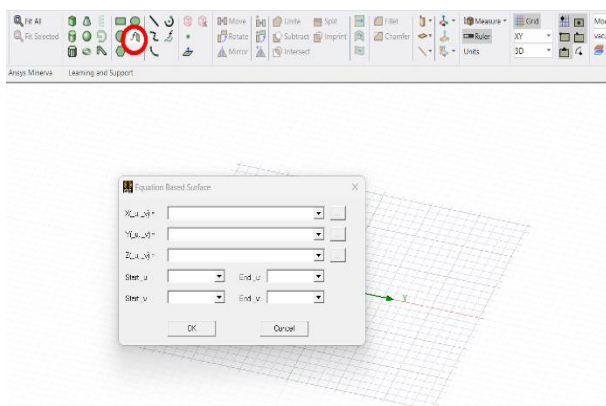


Figure 5

Window for writing equations for the surface

Source: Own elaboration in the Ansys HFSS software

Step by step and with the support of symbology to present figures in two or 3 dimensions, the conditions of the antenna are developed, for example, for the section of the bakelite substrate we select a cube and drag it to the workspace and although at first it is not in the position and size that is required, Double-clicking on the word "Create Box" (red circle in Figure 6) will bring up a window to place it in the desired position, as shown in Figure 6.

Box 6

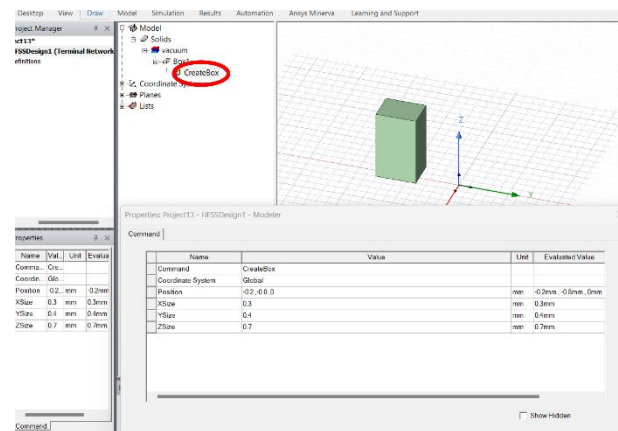


Figure 6

Window to describe substrate location and specifications

Source: Own elaboration in the Ansys HFSS software

To place the material to be simulated, you must right-click on the word "box" and then on the "assign material" section and a window like the one mentioned in figure 7 will be displayed where you simply select "bakelite" as the material to be used and it is automatically loaded to the surface that is being simulated.

Box 7

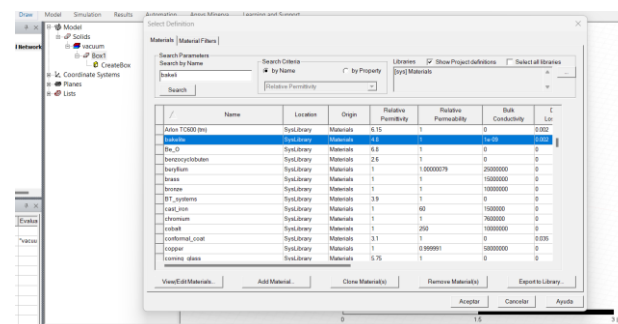


Figure 7

Selection of Bakelite as the material for the antenna substrate.

Source: Own elaboration in the Ansys HFSS software

In the case of the antenna design but with RT duroid 5880 substrate, the same procedure is carried out, but in the previous step the selection of the Rogers RT/duroid 5880 material is carried out, as shown in Figure 8.

Box 8

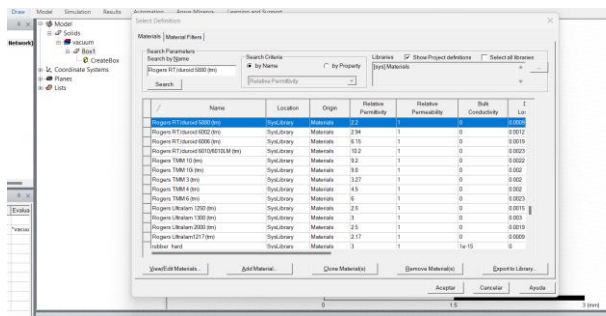


Figure 8

Selection of RT duroid 5880 as the material for the antenna substrate.

Own elaboration in the Ansys HFSS software

At the end of the antenna design with the main characteristics, you proceed to switch to the simulation tab and click on validate (icon marked in green at the top and on the analyze all icon indicated with two gears) as shown in Figure 9.

Box 9

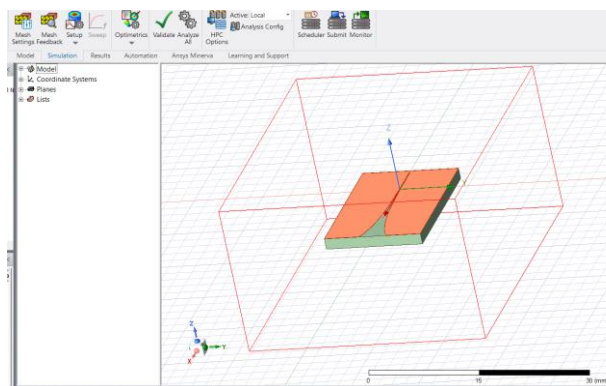


Figure 9

Software simulation window

Source: Own elaboration in the Ansys HFSS software

Depending on the characteristics of the antenna, it is the processing time of the simulation.

Results

Figure 10 shows the simulation result for the S11 parameter which is defined as the reflection coefficient between the port impedance and the network input impedance or simply the reflection coefficient. While Figure 11 shows the result for the VSWR (Voltage Standing Wave Ratio) parameter which refers to a measure of the efficiency of the transmission of a radio frequency (RF) signal.

While figures 12 and 13 refer to the results of the same parameters but for the simulated vivaldi antenna with RT duroid 5880 substrate.

Box 10

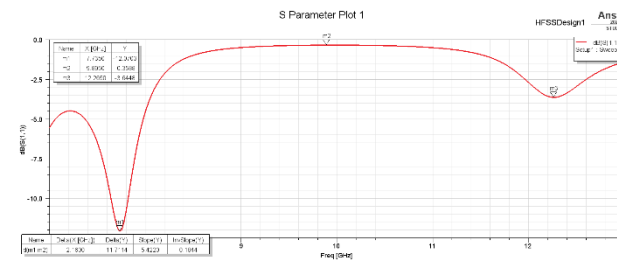


Figure 10

Result of the s11 parameter of the vivaldi antenna with Bakelite substrate

Source: Own elaboration in the Ansys HFSS software

Box 11

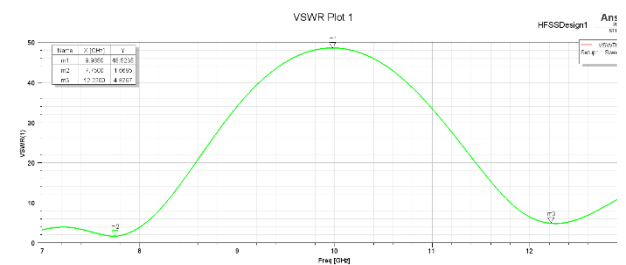


Figure 11

VSWR parameter result of vivaldi antenna with Bakelite substrate

Source: Own elaboration in the Ansys HFSS software

Box 12

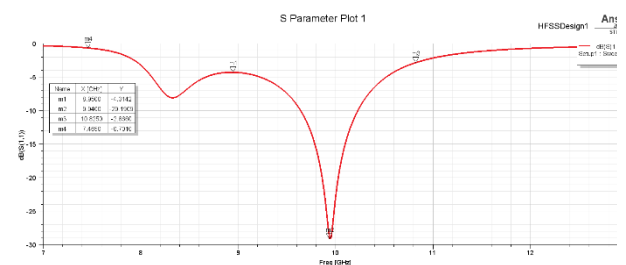


Figure 12

Result of the s11 parameter of the vivaldi antenna with RT duroid 5880 substrate.

Source: Own elaboration in the Ansys HFSS software

Box 13

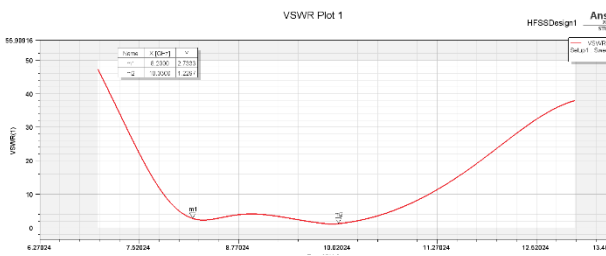


Figure 13

VSWR parameter result of Vivaldi antenna with RT duroid 5880 substrate

Source: Own elaboration in the Ansys HFSS software

Conclusions

The difference between the simulation of both antennas is remarkably large only with the response to the reflection coefficient (parameter s_{11}), in the first case, in which the substrate is bakelite we can observe that the lowest value of the response signal is around 8 GHz while for the simulated antenna with RT duroid 5880 substrate it is very close to 10GHz. It should be remembered that these results are experimental and work continues with them in research projects.

It is important to mention that this work did not receive funding from any research program, however, it is part of a preamble for projects that will be carried out in the following months for the development of new technology.

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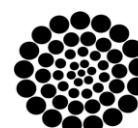
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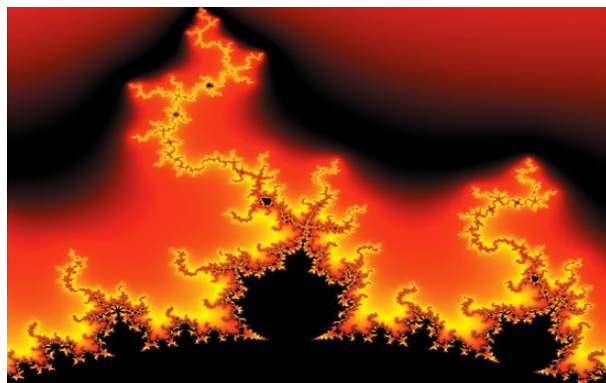


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