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Journal of Systematic Innovation

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The works must be unpublished and refer to topics of electromagnetism, electrical distribution, sources innovation in electrical, engineering signal, amplification electrical, motor design science, materials in electrical power, plants management and distribution of electrical energies and other topics related to Engineering and Technology.

Presentation of the content

In the first article we present, *AutoDrip, automated irrigation system for efficient water use in agricultural cultivation*, *using Renewable Energy in the Sierra Region* by GARCÍA-MORALES, Ana Rosa, AZCONA-RAMÍREZ, Marco Antonio, LÓPEZ-HERNÁNDEZ, Edgardo and ELIAS-MARIN, Oscar, with adscription in Universidad Tecnológica de San Juan del Río, the next article we present, *Characterization of additive manufactured specimens for tensile testing using finite element* by GONZÁLEZ-SOSA, Jesús Vicente, AVILA-SOLER, Enrique and ZAVALA-OSORIO, Yadira, with adscription in Universidad Autónoma Metropolitana, the next article we present, *Fuzzy control design to pose mechanical structures used in solar farms* by CASTILLO-MINJAREZ, José Miguel Angel, GÓMEZ-SÁNCHEZ, Ángel David, MARTÍNEZ-RUEDA, Silvano Librado and CHÁVEZ-ESCALANTE, Luis Geovani, with adscription in Universidad Tecnológica de Tecámac, the last article we present, *Study of the overcurrent protection coordination for radial and ring fed system* by SHIH-Meng Yen, LEZAMA-ZÁRRAGA, Francisco Román, SALAZAR-UITZ - Ricardo Rubén and SANCHEZ-QUINTAL, Ricardo Jesús, with adscription in Universidad Autónoma de Campeche, Campus V.

Content

AutoDrip, automated irrigation system for efficient water use in agricultural cultivation, using Renewable Energy in the Sierra Region

AutoDrip, sistema de riego automatizado para el uso eficiente de agua en el cultivo agrícola, haciendo uso de Energía Renovable en la Región Serrana

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Abstract

In the state of Queretaro, the application of technology in the agricultural sector has become increasingly widespread in recent years, allowing local farmers to improve productivity, reduce costs, and increase efficiency in their crops. Among the most common technologies implemented in the agricultural sector in Queretaro are the use of automated irrigation systems, sensors to monitor soil moisture and ambient temperature, drones for crop analysis, and the implementation of agricultural production management software. The objective of our project is to improve water use efficiency in agricultural cultivation, reducing waste and using renewable energy to increase sustainability and minimize environmental impact through IoT technologies. This will contribute to the development of farmers in the Sierra Gorda with vegetable plots of one hectare or more, who are investing in technological innovation with the use of clean energy, and hoping that the Agricultural Secretariat of the State of Queretaro and the Secretariat of Agriculture and Rural Development will support the project to implement strategies that address the Sustainable Development Goals of the 2030 Agenda.

Irrigation, Agriculture, IoT

Resumen

En el estado de Querétaro, la aplicación de la tecnología en el sector agrícola ha sido cada vez más amplia en los últimos años, permitiendo a los agricultores locales mejorar la productividad, reducir costos y aumentar la eficiencia en los cultivos. Entre las tecnologías más comunes implementadas en el sector agrícola en Querétaro, se encuentran la utilización de sistemas de riego automatizados, sensores para monitorear la humedad del suelo y la temperatura ambiente, drones para el análisis de cultivos y la implementación de software de gestión de la producción agrícola. El objetivo de nuestro proyecto es mejorar la eficiencia en el uso de agua en el cultivo agrícola, reduciendo desperdicios y haciendo uso de energías renovables para aumentar la sostenibilidad y minimizar el impacto ambiental mediante tecnologías IoT. Contribuyendo así al desarrollo de los agricultores de la Sierra Gorda con parcelas de hortalizas de una extensión de una hectárea o más, que le apuestan a la innovación tecnológica con uso energías limpias y esperando que la Secretaría Agropecuaria del Estado de Querétaro y la Secretaría de Agricultura y Desarrollo Rural, le apuesten al proyecto para que implementen las estrategias que atienden los Objetivos de Desarrollo Sostenible de la Agenda 2030.

Riego, Agricultura, IoT

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Introduction

An automated irrigation system is the combination of hardware and software, which aims to optimize the irrigation process according to the conditions and specifications of the crop, being used in places where the lack of water impairs the correct growth and production of crops. The hardware used in recent years is described as Arduino-type temperature and humidity sensors, water pumps, and solar panels, which can be implemented through IoT (Medina and Coral, 2022).

However, it is important for agriculture in the state of Querétaro since it represents a challenge for the agricultural sector according to the report of the Monitor de Sequía en México published by the Government of Mexico (2023), in which it is contemplated that more than 30 percent of the country is being affected by severe drought, more than 50 percent moderate and more than 80 percent is abnormally dry, this makes it vulnerable to moderate droughts and lack of water for agricultural production which allows a more efficient and accurate management of water use in crops.

This is how the automated irrigation system allows a more precise and uniform distribution of water on crops, avoiding water overload and reducing water loss by evaporation and seepage in the soil.

Our proposal compared to other irrigation techniques this has the ability to collect real-time data on soil conditions, to make precise adjustments in the amount and frequency of irrigation, collects information on soil moisture and ambient temperature, these data are processed by the data management system, by implementing a web and mobile application, based on Python, MySQL, HTML, Java, C++. Therefore, by applying the dose of water in the conditions in which it is necessary is considered culturally significant because it is conducive to the generation of behavioral patterns in the production processes of the agricultural sector with efficient consumption of resources, as well as the interaction and communication of stakeholders that directly their exercise benefits the production of food in the Sierra Gorda with the implementation of automated IoT systems like this one.

It should be noted that AutoDrip is designed to facilitate farmers the irrigation process in their crops making use of clean energy and IoT technology, at the same time records and optimizes water consumption, in addition to monitoring environmental factors such as temperature and soil moisture.

These data are obtained after reading the various sensors placed on the crops, are stored in a MySQL database installed on a RaspBerry that are displayed on a Web application interface in real time.

Therefore, the control of these sensors and actuators is done through an Arduino board which allows establishing communication with the Web and Mobile App through the Bluetooth module, as well as sending information for storage.

According to Zamora (2022) in his publication in the AM Queretaro newspaper, he mentions that water scarcity in Mexico also exists because of the 653 aquifers in the country, 275 no longer have water to supply the citizens. If the trend continues, 2022 would represent almost 13 percent less precipitation in Queretaro compared to 2020.

The experts point out that, due to population growth, the high demand for water for agricultural activities and housing settlements, as well as the lags in domestic and industrial treatment and the lack of public policies for water management are factors that put pressure on water supply in Querétaro.

The text presents a theoretical framework that supports the applied knowledge for the development of the system as well as a methodology to develop an automated irrigation system using renewable energy and IoT technology. It starts by identifying the system requirements, then the system is designed and the necessary software to control it is developed. Subsequently, all the components of the system are integrated, testing and validation are performed to ensure that it meets the requirements and works correctly. Finally, the implementation of the system in the place of use and suggestions for the corresponding maintenance.

Theoretical framework

Drip irrigation is a method that consists of applying water in the form of droplets continuously in a place close to the plant, wetting only part of the soil volume (30% of the soil), this is recognized as a highly efficient water-saving irrigation technology worldwide, which has been widely used in arid and semi-arid areas (Wang *et al*., 2022). In this method, a wet bulb is formed in the soil under each drip where the plant develops a larger amount of roots. Drip irrigation has the advantage of using less pressure than other pressurized irrigation methods since it requires a pressure of 1.2 kg/cm. It is suitable for use in irrigation of fruit trees and vegetables (Demin, 2014).

As mentioned by MUNDO RIEGO (2023) another common method is automated irrigation since it is in charge of controlling water distribution. The amount, schedule, location and frequency of irrigation can be chosen. Thus becoming the most productive and comfortable option when watering, since it keeps the lawn, plants and plantations healthy and green; allowing us to save time and effort.

This requires an infrastructure for networking all everyday objects, which are often equipped with some kind of intelligence. In this context, the Internet can also be a platform for devices that communicate electronically and share specific information and data with the world around them. IoT refers to the interconnection of everyday objects through the internet, allowing them to collect and share data, via wireless sensors, mobile networks and actuators.

Modern technology not only helps maintain productivity with limited resources, but can also help observe climate variations, monitor soil nutrients, water dynamics, support data management in agricultural systems, and aid in insect, pest and disease management. Various types of sensors and software tools can be used in data recording and management of cropping systems, ensuring an opportunity for timely decisions (Katimbo *et al*., 2023).

This could help us to cover the water needs of crops as they are related to several factors among them are the climate, and water wastage, in addition to the state of the crop development stages; since all these components facilitate the conservation of moisture in the root system of the plants. Knowledge of the adequate water requirement for crops is essential to improve the efficiency of irrigation systems, providing the plantation with the amount of water necessary to meet its needs, since an excess of irrigation can cause, among other things, the washing of fertilizers, while a water supply lower than the needs of the crop can cause water deficit, and thus, a decrease in production (Tarazona-Meza *et al*., 2022).

With the combination of both, it is necessary to implement the use of renewable energies because they are produced continuously and are inexhaustible on a human scale; they are continually renewed, unlike fossil fuels, of which there are certain quantities or reserves, exhaustible in a more or less determined period of time. The main forms of renewable energies are: biomass, hydro, wind, solar, geothermal and marine energies (Schallenberg *et al*., 2008).

For the specific case of our project we will use an energy source that produces electricity of renewable origin obtained directly from solar radiation through a semiconductor device called a photovoltaic cell, or through a deposition of metals on a substrate called a thin film solar cell (Salamanca-Ávila, 2017).

This source will allow us to keep running the system that will feed the database service created and accessed through a cloud platform. It serves many of the same functions as a traditional database, with the added flexibility of cloud computing (IBM, 2021).

2. Methodology to be developed

According to Maida & Pacienzia (2015) a prototype is a preliminary version of a system for demonstration purposes in which depending on the case we want to test an architecture or technology. However, to develop an irrigation system we use IoT sensors to measure soil moisture and ambient temperature, which allows to automatically adjust irrigation according to the needs of the plants.

In addition, the system uses solar energy for its power supply and can be controlled through a web and mobile application, depending on what is proposed, the stages of the process are described.

2.1 Identification of requirements

First, the irrigation system requirements described in the ERS IEEE 830 format were identified which consisted of the system being capable of scheduling and automatically executing irrigation according to the programmed schedule and duration. The system detects soil moisture and automatically the amount of water is dispensed accordingly. The system allows flexible scheduling and selection of crop-specific irrigation zones. It is weatherproof and able to withstand extreme environmental conditions. For the requirements of the Web and Mobile App, it was determined that it should be easy to use and accessible from any device with an internet connection. It should also allow programming and monitoring of the irrigation system from any location. In the case of hardware and software requirements, the system must be composed of a central controller, soil moisture sensors and irrigation solenoid valves. Once the individual components of the system have been developed, they are all integrated to provide crop monitoring and data analysis to provide useful information on factors influencing irrigation such as humidity and temperature and water consumption.

2.2 System architecture

According to the requirements obtained in the ERS IEEE 830 format, the following model was designed for the construction of the irrigation system.

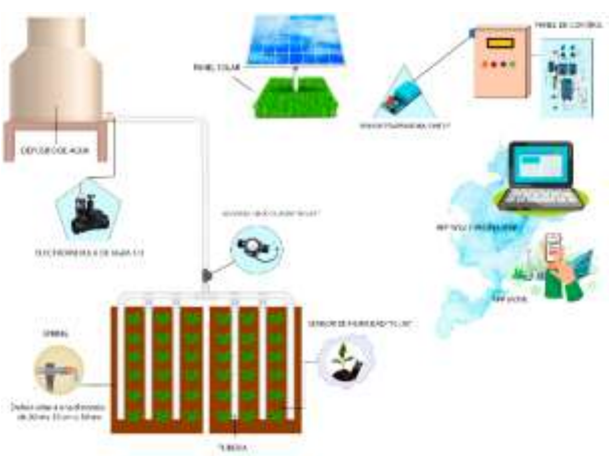

Figure 1 Diagram of the irrigation system architecture
Own Elaboration

2.3 Components

The components that make up the system are as follows.

Soil humidity sensor "Hygrometer FC-28": It allows us to monitor the humidity level of our plants and thus know when it is necessary to irrigate as well as send the readings to a database to have a record of the readings taken.

Humidity and Temperature Sensor "Dht11": The sensor is temperature and humidity uses a digital communication with Arduino, so that we can monitor the environment and climate of place and thus know if they meet the conditions for irrigation.

Solenoid valve "Solenoid Valve 1/2" Solenoid Valve 12v Water Air": It is a device that responds to electrical pulses, and with this we can open or close the solenoid valve thus controlling the flow of water.

Water flow sensor 1/2 "YF-S201B": This flow sensor is responsible for sending information to the database that helps us to know the water consumption, and also sends them to the LCD screen.

Solar panel: The solar panel or solar module is responsible for capturing the energy from solar radiation to take advantage of it, it is stored in a battery that is responsible for powering the system and thus makes use of clean energy.

Arduino Uno: It is an open source microcontroller board based on microchip, the board is equipped with sets of digital and analog I / O pins where you can connect different modules and other circuits, and this helps us to manipulate each of the sensors such as "Temperature sensor and soil moisture, solenoid valves, bluetooth clock module etc.". The Arduino Uno receives or sends information from the data of each sensor and sends them to a Raspberry Pi where the information is stored.

Raspberry pi 4: The Raspberry is responsible for receiving data from the Arduino Uno via Serial and stores them in a local database, from there they are uploaded to a web application where you can view information.

LCD screen: The LCD screen helps us to visualize the data that we receive from the sensors, as well as to visualize a series of menus that the system has.

4-pin push buttons: The push buttons are responsible for manipulating the system and to navigate on the menu that is displayed on the LCD screen, as well as being able to turn on and off the system.

Clock module "DS1302": The clock module is responsible for determining the time or lapses of irrigation at the time it starts and have timers and also keep track of the time when it needs to be watered.

Bluetooth module "HC-06": The bluetooth module allows us to communicate between our Arduino and our mobile so we can control it with a mobile application.

Relay module: It is an electromagnetic device that controls an electrical circuit is a switch that allows to let current pass and also stop it, in this way with the Arduino we can control the pumps or solenoid valves that are connected.

Water pump: It is responsible for distributing water, is activated by the Arduino and Relay these are responsible for turning on and off the pump depending on the parameters sent by the sensors.

Hoses and tubes: They are used to make the connections between the garden and the plants to be watered.

Cables: They are used to connect the sensors and modules to the system and to be able to control them.

Rechargeable battery: It is connected to the solar panel and the system in order to power it and have it always on and water when needed.

Software: In software we use Arduino is a program and its language is based on C, so we can control the system as it has several buttons to navigate the menu of options that has with this we can have control of the sensors of the irrigation system, as well as different modules.

To be able to control it with the mobile application we use a software called Android studio in which different programming languages such as Java and C# are used, with this we can control the irrigation system over long distances in the app you can view the data as well as manage them, the web application has the same functions in this we use the following languages such as HTML, CSS, JavaScript for its operation.

User interface: The user interface is the way users interact with the automated irrigation system. The user interface is manipulated through the web and mobile application that allows users to program the irrigation system, monitor the status of the system and make adjustments as needed.

Internet connection: the internet connection allows the automated irrigation system to communicate with the user interface.

Central controller: is the brain of the system and is responsible for programming and controlling irrigation according to the user's specific requirements.

Soil moisture sensors: used to measure soil moisture and provide information to the central controller to adjust the amount of water dispensed.

Irrigation solenoid valves: used to control the flow of water to each irrigation zone.

Water pump: used to supply water to the irrigation system from the water source.

Filters and water purification devices: used to ensure that the water supplied to the system is clean and free of impurities.

2.4 Software development

The software is capable of reading sensor data, making irrigation decisions based on that data and controlling the irrigation actuators controlled by an HTML Web application, JavaScript C# and an Android Mobile application for which an Apache web server, a MySQL database and a MySQL database are required.

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These components work together to provide an automated and efficient irrigation solution for crops, allowing users to control the irrigation system by accessing it from anywhere, anytime.

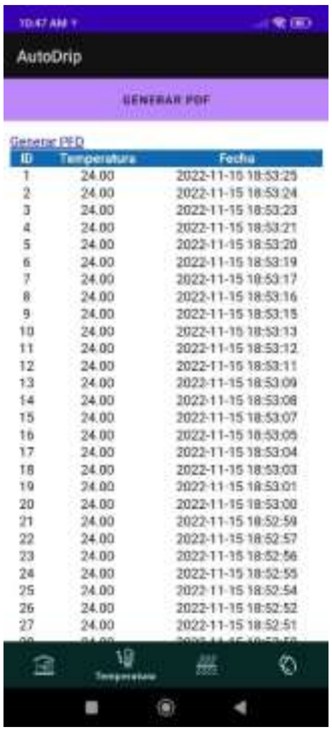

Figure 2 Temperature Mobile App
Own Elaboration

Figure 3 Mobile App Buttons: temperature, humidity, water consumption
Own Elaboration

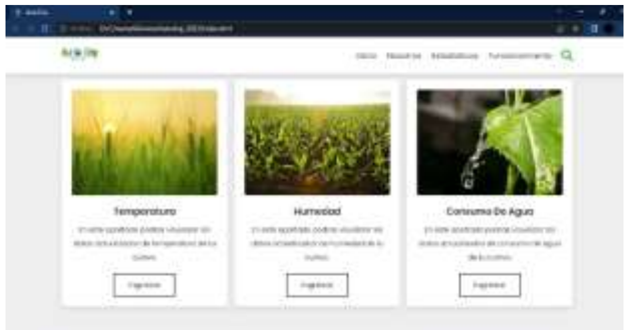

Figure 4 Web App Options to visualize data of temperature, humidity, water consumption
Own Elaboration.

2.5 System integration

AutoDrip uses an Arduino board. This controls the sensors and modules that are connected to it, including a temperature sensor, soil moisture sensor, flow sensor and a clock module that provides the real time used for timing. When the sensors send data, the Arduino receives it and sends it to a Raspberry Pi for storage. From there, the data is sent to a cloud database. In addition, there is an LCD screen that displays a menu of options and allows the sensor data to be viewed in real time. The LCD screen can be navigated with four push buttons that include options for up, down, select and power on/off.

The system also has a Relay that allows to control a solenoid valve. This means that the Arduino can control the solenoid valve based on the data it receives from the sensors. In addition, it is included with a Bluetooth module that allows connection to a mobile application for remote manipulation. Finally, power is given with a battery and a panel to keep it on. When the sensors send data, the Arduino receives it and sends it to a Raspberry Pi for storage. From there, the data is sent to a database in the cloud.

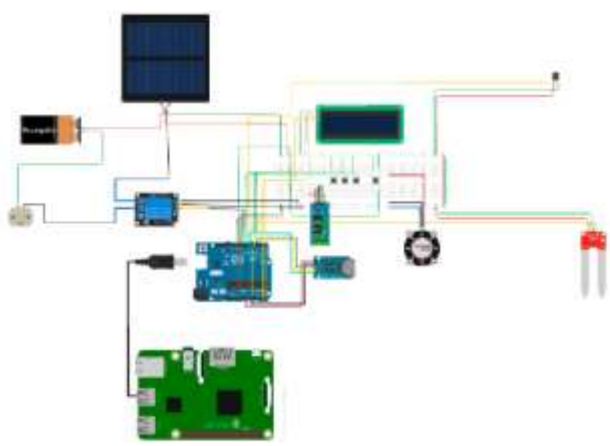

Figure 5 Circuit diagram of the system
Own Elaboration

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2.6 Implementation

The installation was carried out in the space assigned within the UTSJR/UAJ with a dimension of 6mts wide by 8 mts long, housing a total of 30 plants of serrano chili and 30 plants of tomato saladet, distributed in 4 furrows, 8 humidity sensors, as well as 4 electrovalves, a control box that shelters and protects the Arduino components, assembly, connectivity, power supply of the system from inclement weather.

In addition, it has installed a solar panel and the drip irrigation system with a frequency of irrigation. And finally a web server installed with the RaspBerry with access to data in the cloud.

Figure 6 Prototype of a scaled irrigation system
Own Elaboration

Figure 7 Implementation of the automated irrigation system in a chili and tomato field
Own Elaboration

Results

Measurement of temperature as a factor to determine the appropriate value for irrigation to be carried out, showing a graph that allows observing the behavior of the daily temperature, as well as the history of temperatures recorded during the life cycle of the crop.

Figure 8 Temperature data
Own Elaboration

The behavior of one of the factors that determines the water supply for the plant is determined by a parameter previously programmed and adapted to the chili plant, showing a graph per day and a table with historical humidity data.

Figure 9 Moisture data, *prepared by the company*

Finally, water consumption is recorded on a daily and historical basis throughout the entire cultivation process, which will allow us to check whether the resource is really being used.

Figure 10 Water consumption data, *Prepared by the company*

Financing

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Conclusions

The results obtained from the implementation of an automated irrigation system for chili and tomato in the mountainous region of the state of Querétaro can be evaluated in different ways, and it is important to quantify them in order to determine the efficiency and profitability of the system. Some results and possible improvements are presented below:

Improvements in irrigation efficiency have been obtained, which is reflected in reduced water consumption and improved crop quality and yield. It is important to continue evaluating the efficiency of the system over time to identify possible improvements.

The implementation of the automated irrigation system may have reduced labor and energy costs compared to traditional irrigation systems. It is important to continue to evaluate long-term costs and compare them to the costs of other irrigation systems to determine the cost-effectiveness of the system.

The automated irrigation system allows irrigation to be scheduled based on specific crop needs and local weather conditions, which increases the accuracy of water dispensing.

Evaluate the frequency and type of maintenance required to keep the automated irrigation system in operation. Higher maintenance may be required compared to traditional irrigation systems, but the investment in maintenance can be offset by improved irrigation efficiency and reduced long-term costs.

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Characterization of additive manufactured specimens for tensile testing using finite element

Caracterización de probetas elaboradas con manufactura aditiva para el ensayo de tracción utilizando elemento finito

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Resumen

En la actualidad la manufactura aditiva (MA) y la simulación computacional son esenciales en el desarrollo tecnológico para la validación de materiales, con ello asimilar los requerimientos y propiedades de un material antes de ser utilizado para aplicaciones específicas, por lo que en este trabajo se lleva a cabo la caracterización de la probeta para los ensayos de tracción, la cual se elabora en material ABS, utilizando la manufactura aditiva por medio de la I3D (Impresión 3D) y posteriormente se aplica FEM (Método de Elemento Finito), con el propósito de obtener una base de datos con respecto a las propiedades físicas del material al ser sometido a una simulación que representa el ensayo de tracción en materiales plásticos. Con esto se busca implementar nuevas áreas de desarrollo que involucran innovación en la caracterización de materiales utilizados en la manufactura aditiva, incrementando el uso de herramientas computacionales con simuladores en ingeniería. El uso de los datos estará disponible para la comunidad académica e investigadores con la finalidad en enriquecer las aplicaciones con FEM.

Manufactura aditiva, Caracterización, Simulación computacional

Abstract

Nowadays, additive manufacturing (MA) and computational simulation are essential in the technological development for the validation of materials, thus assimilating the requirements and properties of a material before being used for specific applications, so in this work the characterization of the specimen for tensile tests is carried out, which is made in ABS material, using additive manufacturing through 3D printing and then FEM (Finite Element Method) is applied, in order to obtain a database regarding the physical properties of the material when subjected to a simulation that represents the tensile test in plastic materials. This seeks to implement new areas of development that involve innovation in the characterization of materials used in additive manufacturing, increasing the use of computational tools with engineering simulators. The use of the data will be available to the academic and research community in order to enrich FEM applications.

Additive manufacturing, Characterization, Computational simulation

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Introduction

At the Universidad Autónoma Metropolitana, Unidad Azcapotzalco, researchers have applied techniques and methodologies of study with different tools to validate and analyze cases related to science and engineering in different areas, in this work we describe in a general way the use of computational tools through FEM, to characterize and evaluate the plastic materials used in MA with I3D, in order to provide information to the academic and research environment to strengthen innovation and cutting-edge technology.

In the respective to additive manufacturing can be shown to the following works of precursors that were fundamental basis to strengthen this research: (Jung et.al, 2023), mention that, in recent years, it has been shown the potential for lightweighting in load-bearing structural components could be further improved by MA technology. However, the MA process offers a large parameter space that greatly affects the part quality and its inherent mechanical properties. It was concluded that the constraints of stress and uniaxiality conditions are identified with the most influential parameters by correlation analysis. The selected design solutions are further analyzed and compared with generic transition design approaches. The most promising design features (compatible edges, rounded cross-section, column connection) are then interpreted into structural elements, leading to an innovative generic design of the load introduction region that yields promising results after a proof-of-concept study.

(Sponchiado et.al, 2023), allude that additive manufacturing by material extrusion allows combining materials in the same nozzle during the deposition process. This technology, called material coextrusion, generates an extended range of material properties, which can gradually change at the design level, ensuring a combination or further bonding/interlocking between different materials. To take advantage of the opportunities offered by these technologies, it is necessary to understand the behavior of the combined materials according to material fractions. In their work, two pairs of compatible materials, namely polylactic acid (PLA)-thermoplastic polyurethane (TPU) and acrylonitrile styrene acrylate (ASA)-TPU, were investigated by changing the material fractions in the coextrusion process.

An original model describing the distribution of the materials is proposed. Based on this, the mechanical properties were investigated by analytical and numerical approaches. The analytical model was developed under the simplified assumption that the coextruded materials are an array of rods, while the more realistic numerical model is based on homogenization theory, adopting the FEM of a representative volume element. The analytical and numerical models show similar trends and it can be assumed that the finite element model has a more realistic behavior due to the higher accuracy of the model description. In this initial work, the results show good agreement between models and experiments, providing useful tools for designers and contributing to a new branch of additive manufacturing research.

(Ringel et.al, 2023) point out that, the pressure vessel qualification process in general is subject to governmental restrictions. Therefore, introducing MA components to the market is challenging due to incomplete standardization. To increase component safety and confidence, predetermined failure points can be integrated by design using direct manufacturing methods. A predetermined failure point via a surface notch is an option to avoid dangerous part failures (e.g. explosion) and increase safety. FEM is used for investigations on the influence of surface notch geometries applied to wall structures on the structural tension camber. Evaluation of the fracture surface and plastic elongation by optical microscopy and three-dimensional surface scanning elucidate the material behavior.

Analytical and experimental approval of an integrated predetermined failure point for static overload is achieved without reducing the maximum value of burst pressure. The integration meets all theoretical structural strength requirements. All tested specimens meet expectations for static strength and failure behavior. As expected, the elongation of the component decreases by using notches in the surface to cause failure.

The results lead to a proposed guideline for the application of an integrated predetermined failure point by using a surface notch.

(Bagewadi et.al, 2023) suggest that auxetic structure MA is gaining importance in various fields ranging from structural materials to biomaterials. This work proposes a novel design of auxetic structure with regular honeycomb, i.e. hybrid auxetic structure. All the models are fabricated in extrusion based MA technique using polylactic acid (PLA) material. A comparative study was carried out on 3D printed samples that were subjected to uniaxial tensile loading. To understand the effect on functional and mechanical properties, a tool path strategy with single-pass and zigzag tool paths was proposed. Solid material properties were used FEM to compare with experimental results. Experimental results indicate that the hybrid structure requires more load than the auxetic structure. The ultimate tensile strength (UTS) of the hybrid structure was 32% higher than that of the auxetic structure. The FEM results agree well with the experimental results. The observation reported in this paper will help to frame the design rules and selection of MA, processes for applications ranging from structural protective sandwich constructions with low density cores to tissue engineering and regenerative medicine structures.

(Wang et.al, 2023) indicate that, large sizes and destructive elements hindered standard uniaxial testing for in-service parts fabricated by laser additive manufacturing (LAM). Therefore, small-scale testing techniques, such as small punch tensile testing (SPT), were widely employed to evaluate local mechanical characteristics. In this study, layer-by-layer fabrication of Hastelloy X was produced by LAM-assisted ultrasonic micro-forging (UMFT) treatment.

The microstructure and fracture of the components showed that UMFT successfully reduced LAM defects; the defect distribution characteristics of sample blocks and SPT specimens were determined by the extreme value method (EVM); the effect of defect characteristics on strength was evaluated by Pearson's correlation coefficient (PCC). The results of various error evaluations showed that the proposed models had higher accuracy and stability than classical SPT models; According to the defect distribution in LAM blocks, the estimation error of total strength of LAM Hastelloy X was within 2%.

The simulation analysis with FEM, allows to develop iterations from the computational point of view (Soratos & Masayuki, 2020), to favor the study of test specimens or final products with a theoretical-experimental validation. In this work it is carried out with the pre-set conditions for the mechanical tensile test on plastic materials.

The phenomenon of analyzing with FEM in three dimensions favors the study of the specimens (Castorena *et al.*, 2011) under the mechanical stresses in the tensile test, for this study only makes use of the data when the force is exerted on the Y axis, however, it is possible to analyze the stresses at different points and areas of action under different loads, which allows a greater amount of data to validate the test.

For the FEM simulated test, the specimen is designed in flat form with the specifications of the ASTM D638 standard, which allows performing the procedure in a specific way in the application of the loads required for the tensile test, whose design was essential for the development of the methodology in the simulation (Mansilla, 2001).

One of the advantages with FEM for the present work is the use of different numerical models at the time of performing the process in the simulation (Hernández & Cárdenas, 2018), managing to satisfy different parameters considered in the specimen for the simulated tensile experimentation, taking into account that the results have linear ranges, reaching the point at which the materials do not exceed the corresponding creep limit.

In addition, FEM is a tool used in engineering to obtain approximations (Ravindranath & Sidda, 2016) and validate elements within a component subjected to both internal and external loads, depending on the case study, with the purpose of optimizing the analysis.

The estimation of mechanical behavior, as shown in this work, is based on clearly specifying the models to be simulated (De Abreu & Pertuz, 2014) and their dimensional characteristics, as well as the control parameters in the application of mechanical tests such as tensile tests, for this case study.

The following paragraphs describe the equipment used, the shape of the specimen, the loads to which they are subjected in the simulation, obtaining data to represent them in the results.

Methodology

This work describes the types of materials used in additive manufacturing, through 3D printing, with the purpose of evaluating each of these with the tensile test in plastic materials and determine the physical properties of each specimen evaluated with the Finite Element Method (FEM), through this identify possible applications in different areas of engineering.

Additive manufacturing: is a tool in the pillars of Industry 4.0, which allows innovation in specific applications in technological processes. In other words, it represents improvements compared to conventional processes, where energy savings, cost reduction and time compacting are achieved in the production of specimens or products for their commercialization.

In the industry, the use of this tool has been agreed upon to improve production processes and to analyze quality processes in the design of test specimens for use as final products. In the academic sector, in educational institutions, it is an important part of the teaching-learning methodologies in the knowledge of new innovation technologies. And for research, it is essential to have additive manufacturing at the time of carrying out analysis in case studies that would be complicated to obtain by conventional manufacturing and with additive manufacturing is achieved by reducing manufacturing times and have specimens with the required specifications for the corresponding study.

3D Printing (I3D) and equipment to be used: I3D is the application of additive manufacturing to obtain physical models with the desired parameters and specifications, the following steps should be considered to develop a prototype or functional product:

- Sketch design for the specimen.
- Modeling in three dimensions with computer aided design (CAD) software.
- Export the model in stereolithography (stl) format.
- Analyze in the 3D printer software.
- Configuration of parameters for printing.
- Final product.

I3D makes use of various materials, among the most common are: Acrylonitrile Butadiene Styrene (ABS), Polylactic Acid (PLA), Nylon, Polyethylene terephthalate (PET), Acrylonitrile Styrene Acrylate (ASA), Polystyrene (HIPS), Polyamide (PA), Polypropylene (PP), Polycarbonate (PC), which are the most common in the field of I3D. Each of these materials has specific properties and applications that will depend on the conditions to which the products obtained with these materials are subjected.

On the other hand, the equipment to be used in the elaboration of the tensile specimens, for the case study, is a Zortrax model M200 Plus machine, whose characteristics are described in Table 1 and the equipment is shown in Figure 1.

Feature	Value/unit
Working volume	200x200x180 mm
Material diameter	1.75 mm
Nozzle diameter	0.3 mm, 0.4 mm, 0.6 mm
Connectivity	Wi-Fi, Ethernet, USB
Technology	LPD (Layer Plastic Depositiom)
Resolution	90-390 microns
Tem. Maximum Extruder Tem.	290°C
Max. Max. platform temp.	105°C
AC Input	110 V
Power	320 W

Table 1 Printer characteristics
Source: https://zortrax.com/3d-printers/m200-plus/

Figure 1 3D Printer, Zortrax M200 Plus
Source: Authors

An important part of this work is to consider that the equipment shown in Figure 1 is used and that, if you want to obtain specimens with other 3D printers, you must take into account the processing software, which has different parameters in each of the equipment for I3D, and the control variables of the equipment, to obtain parts with the same specifications.

The use of I3D, favors the analysis for case studies related to the characterization of materials, since it allows identifying the way in which a specimen can be processed with the different materials used in additive manufacturing (Zmindak *et al*., 2020), achieving improvement trends in the study of materials.

Physical properties of plastic materials: the materials used for the study are ABS and PLA, so the properties to be compared in the FEM study should be mentioned, Table 2 shows the data for each of these materials and the properties to be evaluated.

Material	Property	Value/unit
ABS	Tensile stress	30.46 [MPa]
	Deformation	4.52 [%]
	Hardness	69.2 Shore D
	Flexural modulus	1.08 [GPa]
PLA	Tensile stress	47.95 [MPa]
	Deformation	3.8 [%]
	Hardness	79.8 Shore D
	Flexural modulus	1. 47 [GPa]

Table 2 Printer characteristics
Source: https://www.matweb.com/index.aspx

Characterization of plastic materials: it is a comparative evaluation of the plastic materials used in this research with additive manufacturing, carrying out the comparison of these by statistical means, determining the value in the physical properties of them. The characterization is carried out with destructive testing, tensile, by means of digital tools, FEM, based on ASTM standards (Kelly *et al*., 2018).

The tensile test is established under theoretical models mentioned below, where the specific variables for the development of the test are observed (Lohdy *et al*. 2020), (Cakmak *et al*., 2022), which will be evaluated with FEM.

One of the mechanical properties is the shear modulus, which can be obtained by means of equation 1, as well as the elongation ratio, with equation 2.

$$G = E/(2(1+v)) \quad (1)$$

$$\varepsilon_y = \Delta L/L \quad (2)$$

For which the stress and strain components are established, according to the symmetry in anisotropic materials, as shown in Table 3.

Material symmetry	No symmetry	Oriented-monoclinic	Oriented-orto
Constants ≠0	36	20	12
σ_1, σ_2, σ_6	≠0	≠0	≠0
σ_3, σ_4, σ_5	=0	=0	=0
ε_1, ε_2,ε_3, ε_6	≠0	≠0	≠0
ε_4, ε_5	≠0	=0	=0

Table 3. Stress and plane strain
Source: Design and analysis of materials Editorial Reverte

Table 3 shows the parameters to be analyzed with the FEM tool, according to the conditions in the specimen characterization, and to validate the information of the material subjected to the simulation tests.

Three-dimensional model: the model is made with a CAD modeler, whose image is shown in Figure 2.

Figure 2 Tensile specimen in the CAD modeler
Source: Authors: Authors

The model was made according to the characteristics established in the ASTM-D638 standard, taking into account each of the classifications for types I, II, III, IV and V, for the application in the characterization of the specimen.

Application of FEM: to apply the FEM tool in each of the test specimens, the parameters to be analyzed are as follows for the ABS material are shown in Table 4. Representing P (parameter), VM (Von Mises), EY (Normal stress in Y) and DS (displacement in Y).

Property	Load	Variable (Mesh in %)				
	[kN]	MP 2	MP 4	MP 6	MP 8	MP10
VM [MPa]	0.05	1.42	1.23	1.19	1.17	1.15
	0.1	2.84	2.46	2.40	2.33	2.30
	0.2	5.68	4.93	4.74	4.66	4.59
	0.25	7.1	6.16	5.92	5.83	5.74
	0.5	14.19	12.32	11.85	11.66	11.48
	1	28.38	24.64	23.69	23.32	22.96
	2.5	70.96	61.62	59.24	58.3	57.4
	5	141.9	123.2	118.5	116.6	114.8
	10	283.8	246.4	236.9	232.2	229.6
	15	425.8	369.7	355.5	349.9	344.4
EY [MPa]	0.05	1.44	1.22	1.21	1.91	1.16
	0.1	2.87	2.44	2.43	2.38	2.32
	0.2	5.74	4.88	4.85	4.76	4.64
	0.25	7.17	6.10	6.06	5.96	5.80
	0.5	14.34	12.2	12.13	11.91	11.6
	1	28.69	24.41	24.25	23.82	23.19
	2.5	71.72	61.02	60.63	59.56	57.98
	5	143.4	122	121.3	119.1	116
	10	286.9	244.1	242.5	238.2	231.9
	15	430.4	366.2	363.8	357.4	347.9
DS	0.05	0.053	0.053	0.052	0.052	0.052
	0.1	0.11	0.10	0.10	0.10	0.10
	0.2	0.21	0.21	0.21	0.21	0.21
	0.25	0.26	0.26	0.26	0.26	0.26
	0.5	0.53	0.53	0.52	0.52	0.52
	1	1.06	1.05	1.04	1.04	1.04
	2.5	2.65	2.63	2.60	2.57	2.59
	5	5.30	5.27	5.19	5.19	5.18
	10	10.59	10.53	10.38	10.38	10.35
	15	15.9	15.8	15.58	15.58	15.53

Table 4 Parameter values obtained with 2-8% meshed FEM, ABS material.
Source: Authors

Table 4 identifies the data collected after the application of the tensile test in a virtual way (simulation), with the purpose of identifying the optimum values for the material, load and type of mesh for each classification in percentage of ABS.

Figure 3 shows some examples of the application of loads on the specimen and the meshing of the specimen.

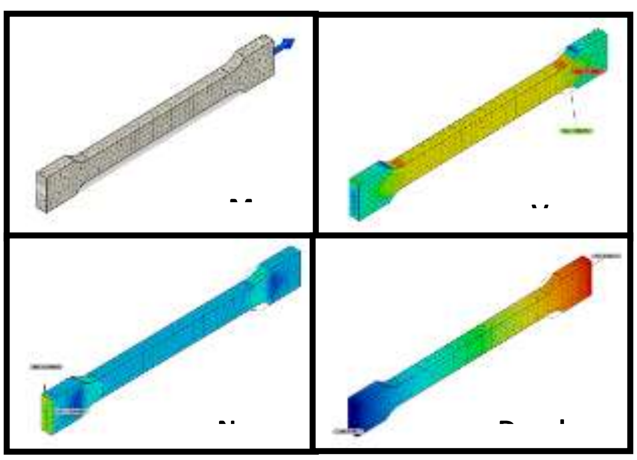


Figure 3 Application of FEM in ABS material
Source: Authors

The simulation with the FEM tool analyzes the Von Mises stress, being an anisotropic material, normal stress in Y, corresponding to the tensile test simulation and the displacement in the Y-axis. The data obtained will be analyzed and discussed in the corresponding sections.

Figure 4 shows the percentages applied to the ABS material with the similarity in the meshing.

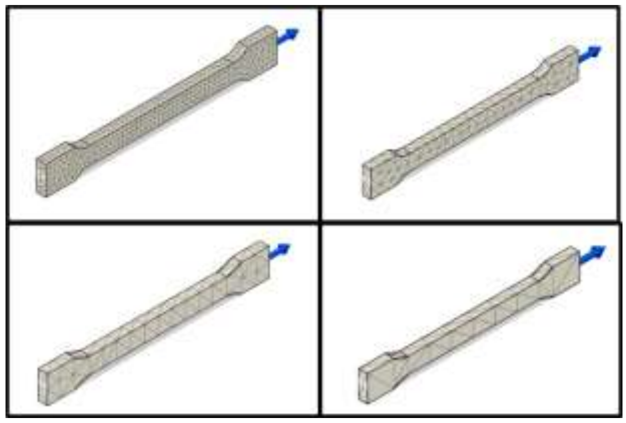


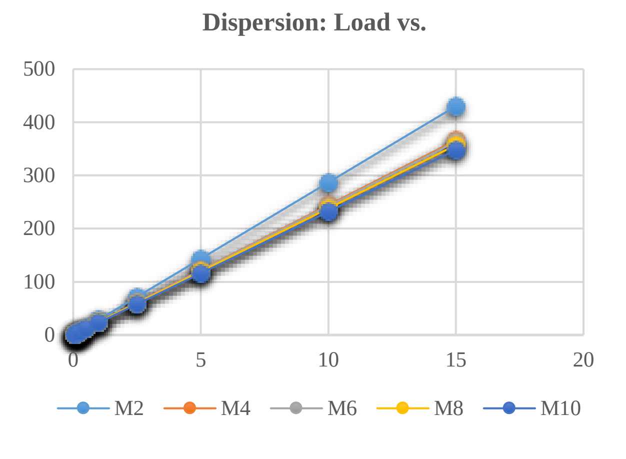
Figure 4. 2-10% mesh
Source: Authors

The meshing performed by means of the FEM simulator allows visualizing the percentage of filling of the specimen to carry out the characterization and verify the values of the mechanical properties according to the elements considered for the simulation (Castaño *et al*., 2020).

The following section analyzes the data obtained in the simulation and the optimization of the ABS material for its use in specific cases that meet the specifications, both of the material and of the operating conditions in the tensile tests for each of the specimens evaluated.

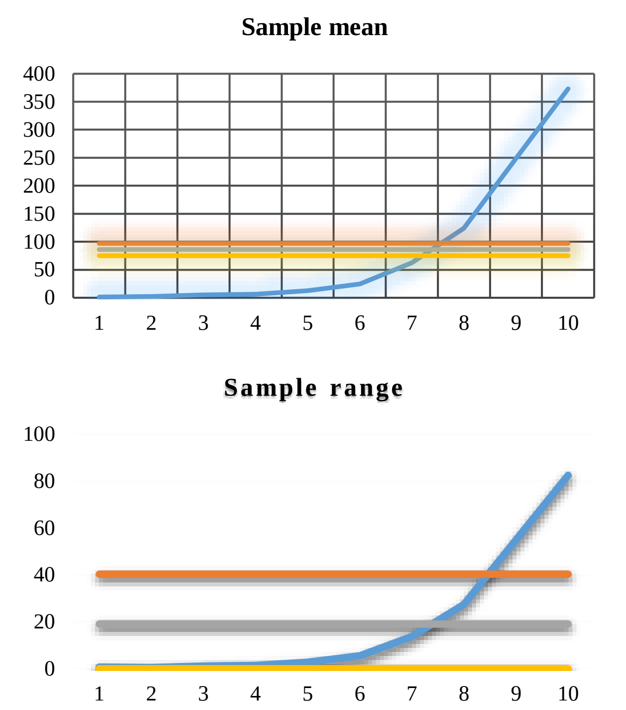
Results

Firstly, the scatter plots corresponding to the load vs. the type of meshing are shown, validating that its behavior is linear, which was obtained with respect to each of the loads applied in the simulation by means of FEM. The graphs are shown in Figure 5.



Graph 1. Load vs. 2-10% meshing graph.
Source: Authors

On the other hand, there is a graph, figure 6, with respect to the mean of the sample (M2) and the range of this sample in order to establish statistical points for the validation of future simulations with other materials with similar specifications to those of ABS.



Graph 2 Graph of mean and range for M2
Source: Authors

Next, the data is represented by means of information collected in Table 5, which indicates the stress values in Y, compared with the theoretical-experimental data, whose value corresponds to 30.46 [MPa].

PF	Load	Simulation				
	[kN]	M2	M4	M6	M8	M10
EY	1	28.69	24.41	24.25	23.82	23.19
[MPa]	1.25	71.72	61.02	60.63	59.56	57.98

Table 5 Simulated Y-stress values with theoretical
Source: Authors

The purpose of Table 5 is to offer the data that represent the characterization of the specimens subjected to tensile stress, from the simulation point of view with the FEM tool and thus establish the amount of filler in a specimen manufactured with additive manufacturing with I3D.

Using the numerical interpolation method, the value of the load to which the specimen should be subjected is obtained, together with the meshing percentage and thus provide the optimization in the characterization with FEM, as shown in Table 6.

PF	Load	Simulation	
	[kN]	M2	E[%]
EY	1	28.69	5.81
[MPa]	1.01	30.46	0
	1.25	71.72	135.45
	Carga	M4	
EY	1	24.41	19.86
[MPa]	1.04	30.46	0
	1.25	61.02	100.32
	Carga	M6	
EY	1	24.25	20.38
[MPa]	1.04	30.46	0
	1.25	60.63	99.05
	Carga	M8	
EY	1	23.82	21.79
[MPa]	1.05	30.46	0
	1.25	59.56	95.53
	Carga	M10	
EY	1	23.19	23.87
[MPa]	1.05	30.46	0
	1.25	57.98	90.34

Table 6 Percentage of error in the evaluation
Source: Authors

With the information provided in Table 6, it is determined that M2 with a load of 1 kN corresponds to the parameter that optimizes the system for the material to be used in tensile effects. Taking into account that the load range required for this solicitation, characterization of the ABS material, is in [1-1.01] kN. If a higher resistance is required, the M10 would be used with stress in the range of [23.87-30.46]. However, with the results obtained in this study, it is possible to establish characteristic values for different applications where a material, ABS, is required with evaluated stresses and loads.

On the other hand, we have the data where the amount of elements that are contemplated in the simulation to optimize the results are identified, which have the opportunity to be modified to improve in each of the simulation processes the results at the moment of executing the FEM simulation with the corresponding variables, in table 7, it is observed as mentioned.

Mesh	Nodes	No. elements
M2	6127	3490
M4	978	441
M6	454	195
M8	401	170
M10	235	94

Table 7 Variables in FEM simulation
Source: Authors

Table 7 represents the control to be compared with the meshing and the infill content in the I3D, which means that as the nodes and elements increase the percentage of infill is higher, having as equivalences M2-100% infill, M4-80%, M6-60%, M8-40% and M10-20%.

It is important to highlight that in the simulations the number of elements and thus the nodes can be modified to optimize the simulations and obtain standardized data to make comparisons between different materials.

The use of the FEM tool in the characterization for a mechanical tensile test has the advantage of speeding up the process and obtaining values of the materials being evaluated to identify the application according to the values obtained, according to the variables to be analyzed.

Conclusions

A mechanical test known as traction has been applied in a general way for materials engineering in technological innovation processes such as additive manufacturing with I3D, through a simulation tool such as FEM, obtaining favorable results to compare what has been done with theoretical experimentation and formulating new trends of analysis and characterization of engineering materials.

This leads to standardize the use of I3D with materials that meet the basic properties for its performance as a final product. In this sense, this work seeks, at all times, to provide data that other researchers and teachers of academic institutions can take advantage of for their performance in the field of engineering applications.

The use of FEM currently favors the time and space of engineering execution, taking into account that the characterization of engineering applications is developed with specific criteria in the evaluation, such as physical, chemical, optical, thermal properties, among others, with the simulation tool.

An important point with the use of FEM simulation lies in controlling the percentage of mesh, nodes and elements in the test specimen, with which the optimization of the object is achieved according to the mechanical stresses, for this case study, with respect to the tensile test.

The results showed a congruence with the behavior of the test and the simulation, appreciating at all times that the higher the mesh percentage, the more fragile and the lower the stress value in the area of action (Y).

The data obtained are used to determine the application of the specimen, with respect to the resistance of the material and the deformation it presents. This achieves the interest of the research developed in this work to strengthen the research communities in additive manufacturing with I3D.

In relation to the graphs there is a linear trend, for dispersion, with the behavior of the material when subjected to the test and also the graph that allows to increase the application of statistics to the characterization of the ABS material and the possible evaluation of other materials with this tensile test in the FEM simulator, control graphs were used to identify trends in terms of means and ranges for each of the chosen meshes and their similarity with the percentage of filler in the I3D.

The improvements to be made are directly focused on the use of the FEM software modules to optimize the greater amount of parameters and variables indicated in the simulations, in addition, to offer integrating projects in the academic and research communities to strengthen the use of innovation technologies, such as the MA with I3D, the numerical analysis to verify and validate the data obtained in each one of the case studies immersed in the applied engineering.

In the future, FEM will be applied with other materials used in the MA to enrich and increase the databases in the characterization for the tensile test and later other destructive mechanical tests. Without losing sight of the application of statistics and numerical analysis as engineering tools in the validation and optimization of engineering processes.

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Fuzzy control design to pose mechanical structures used in solar farms

Diseño de un control difuso para posicionar estructuras mecánicas empleadas en granjas solares

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Abstract

Solar panels have problems in terms of the optimal capture of solar energy, reducing their efficiency due to the static position they maintain throughout the year. This article presents the proposal for the development of a fuzzy control to position a mechanical structure, which supports a solar panel seeking to obtain maximum capture in solar farms. The fuzzy control law defines rules that together cause a nonlinear control law by evaluating the performance of the controller through graphics and its simulation in the MatLab Simulink® software. The mechanical structure used has an arrangement of photoresistors at the ends of the surface, which determined the desired elevation angle, generating the control setpoint. Three experiments were developed to validate the operation of the resulting controller, concluding that the diffuse system decreases the position error with respect to the incidence of solar radiation on the photovoltaic cells and the rotational movement of the Earth.

Solar panel efficiency, Nonlinear control law, Fuzzy logic

Resumen

Los paneles solares presentan problemas en cuanto a la captación óptima de energía solar, reduciendo su eficiencia debido a la posición estática que mantienen a lo largo del año. En este artículo se presenta la propuesta del desarrollo de un control difuso para posicionar una estructura mecánica, la cual soporta un panel solar buscando obtener la máxima captación en granjas solares. La ley de control difuso define reglas que en conjunto causan una ley de control no lineal evaluando el desempeño del controlador mediante gráficos y su simulación en el software MatLab Simulink®. La estructura mecánica empleada cuenta con un arreglo de fotorresistencias a los extremos de la superficie, lo cual determinó el ángulo de elevación deseado, generándose la consigna de control. Se desarrollaron tres experimentos para validar el funcionamiento del controlador resultante, concluyendo que el sistema difuso, disminuye el error de posición con respecto a la incidencia de la radiación solar en las celdas fotovoltaicas y el movimiento rotacional de la Tierra.

Eficiencia del panel solar, Control no lineal, Lógica difusa

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Introduction

Currently, most of the structures that support solar panels are not mobile or have a manual movement system, causing maximum energy collection only when the sun's rays are perpendicular to the panel surface. In addition, the collection time is limited due to the lack of automatic adjustment in the orientation of the mechanical structure. Based on this drawback, we propose the application of a set of fuzzy rules that minimize the orientation error at any instant of time.

The operation of fuzzy control is based on the theory of fuzzy sets, which defines elements such as: membership functions, variables and linguistic terms and inference rules, whose assignment is carried out by an expert in the systems to be controlled (Amato, 2006; Cirstea *et al*., 2022; Harris *et al*., 1993). Some of the current applications of fuzzy controllers are focused on electrical systems (Boujoudar *et al*., 2023; Chaithanakulwat *et al*., 2023), to optimize energy demands. Thus, the advantage of the methodology proposed in this work is to dispense with a dynamic mathematical model of the system to be controlled (Amstrom & Murray, 2008; Jack, 2001). However, for future applications, it could be combined with a mathematical model in order to robust the closed-loop system, implying a decrease in the steady-state position error, (Slotine & Li, 1991; Tsui, 2022; Vidyasagar, 1993; Vukic *et al*., 2003). A possible disadvantage, however, is that the increase in inference rules generates unnecessary computational load and does not ensure higher system accuracy. This offers the possibility of embedding the system in a low performance device as presented by (Alamouti *et al*., 2023).

The proposed methodology will be applied to a mechanical structure that provides support and protection to two solar panels, allowing maneuverability in the specified range of angular movement in an interval between $-80° \leq \theta \leq 80°$.

The mechanical structure supporting the solar panel is schematized with which, the possibilities of its mobility are analyzed. The essential characteristics of the fuzzy controller applied to the mechanical structure are also discussed.

On the other hand, the results obtained under simulation of the performance of the established fuzzy rules are presented, using MatLab Simulink® software. Finally, the conclusions of this work are presented.

Operating conditions

There is a restriction of the sun movement, since it has only the direction from east to west. For this reason, the structure of the solar positioner has a rotational movement conditioned to rotate a certain number of degrees of freedom (Lewis, 2003), forming an angle of elevation with respect to a horizontal plane. In this way, the angular value can be measured and thus generate the rotation of the structure to the desired position. Implying that the angular error at infinite time is zero, as stated in equation (1).

$$\lim_{t\to\infty} e(t) = 0 \tag{1}$$

Figure 1 shows the desired elevation angle which is a function of the perpendicularity of the receiving surface (solar panel) with respect to the sun's rays, the mathematical expression that determines this condition is:

$$N \circ r = 0 \tag{2}$$

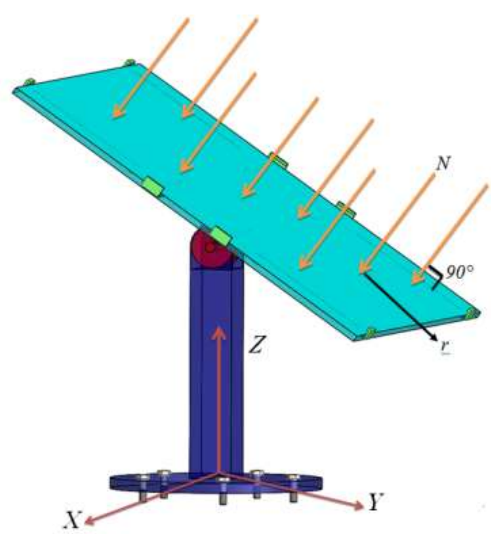

Figure 1 Perpendicularity condition. Where r, is a coplanar vector and N, the vector normal to the surface of the panel
Own source

Figure 2 shows the assignment of a global reference frame in the base denoted by the triad {X, Y, Z}, as well as the centers of mass of each of the links, their lengths from the global reference frame to the centers of mass lc1 and lc2, and the angles of movement.

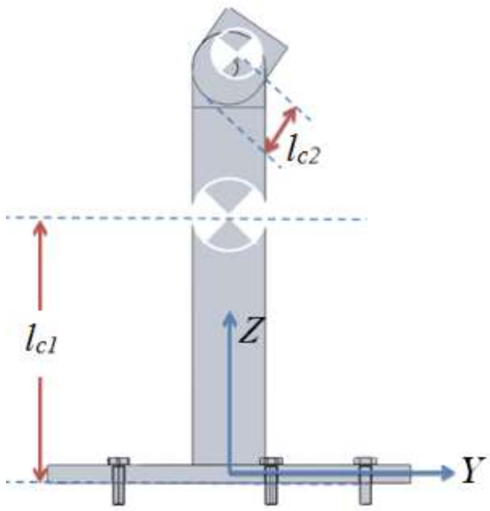

Figure 2 Diagram of the structure
Own Source

The mechanical structure has the following conditions:

1. The angular range of motion prevents the receiving surface (solar panel) from colliding with the mechanical structure.

   The configuration of the input signals obtained in a pair of photoresistive arrays, located at the ends of the receiving surface.

2. The orientation of the photoresistive arrays is in an east-west direction.

Methodology to be developed

Fuzzy Control

MatLab Simulink® software was used to observe the performance of the proposed controllers with the fuzzy model.

In order to obtain the maximum solar energy collection with the photovoltaic panel, it is necessary the existence of a set of fuzzy rules that define a control law, which commands the actuator and thus, the mechanical structure can be positioned at an appropriate angle. The system is in closed-loop configuration (Amstrom & Murray, 2008; Tsui, 2022) to gradually decrease the angular positioning error.

The principle of the operation to properly position the solar panel is based on the processing of the electronic signals transmitted by the photoresistors.

Taking into account the fact that, when receiving a higher amount of illumination, the photoresistors decrease their resistive value and determine the basis for the creation of the set of inference rules that control the elevation angle. In addition, the inputs are selected based on the resistive value delivered by each photoresistor (the output is the angular position).

According to the model to be controlled, the degrees of membership are assigned based on the resistive value, defining the ideal set as the one with the lowest resistive value, in a range from 0 to 100Ω. This condition occurs when the luminosity has a greater incidence on some photoresistance, not being an impediment to the reassignment of a new domain of definition for the resistive range. Thus, a set of six membership functions is generated for each photoresistor, triangular at the center and trapezoidal at the ends to avoid inconsistency in the data, as shown in Figure 3.

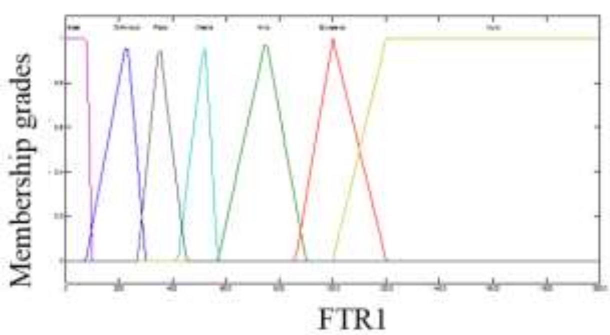

Figure 3 Membership functions corresponding to the inputs
Own Source

While the membership functions for the output are measured in degrees (angular), in a range of [-80°, 80°], with the intention of having a tolerance of ± 10° at each end of the receiving surface to avoid collisions with the structure. The negative references indicate the movement that the surface will generate towards the east, otherwise, the positive references will generate movement towards the west.

Figure 4 shows the membership functions defined for the output: where it is possible to notice a set of 31 linguistic terms, with which the inference rules are assigned to merge the inputs and the output. Subsequently, the Center of Mass (COM) method must be applied to defuzzify the values and issue a change command to the actuator.

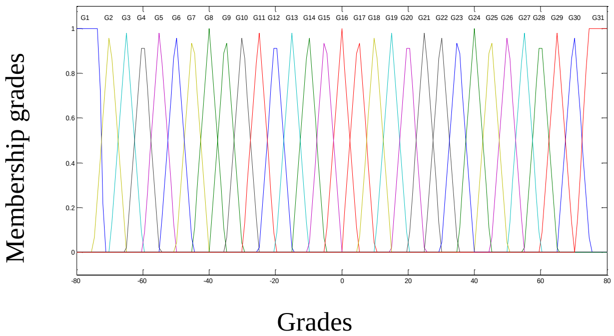

Figure 4 Output membership functions
Own Source

The assignment of the rules corresponding to the fuzzy control, starts from considering comparisons in adjacent pairs of photoresistances. Table 1 shows one of 10 relations created, defining the following linguistic terms: Ideal, Tiny, Little, Medium, High, Excessive and Null.

The inputs are set at 10° for each photoresistor, representing its sensing range from 0 to 2000Ω. The different outputs (G), are represented by intervals of 10° each, generating an overlap of 5°, starting with G1 (-80°,-70°), G2 (-75°,-65°), G3 (-70°,-60°) and so on.

There is the possibility of validating the adaptability of the controller to different situations, therefore, three states of motion within the previously established range were considered: initial, intermediate and final, whose control surfaces are shown in the results section.

To validate that the resulting control surfaces comply with the control objective established in Eq.1 of the operating conditions, three experimental tests were performed aligned to the previously determined motion states.

Results

The resulting control surfaces for the proposed motion states were as follows:

Initial: Considering active two photoresistors, specifically FTR9 and FTR10, the controller result was a rotation in -X direction (measurements in the range of [0°, 80°]). The control surface obtained is shown in Figure 5.

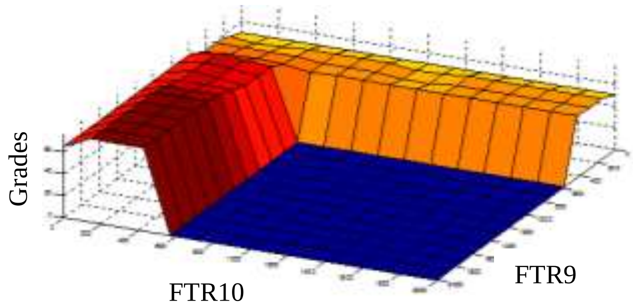

Figure 5 FTR9-FTR10 relationship surface
Own Source

Intermediate: It considers the central photoresistors active, inputting the input signals to the fuzzy controller, which generated as a response the positioning at 0° with respect to the Z axis. Figure 6 represents the behavior of this state of motion.

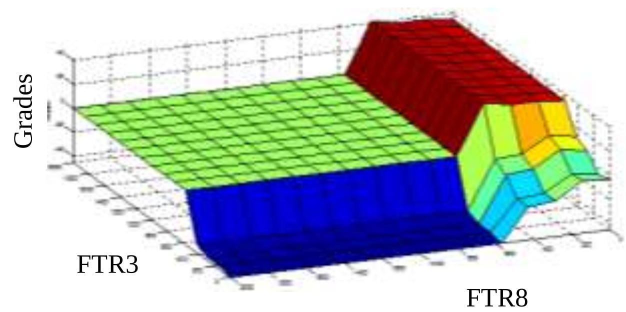

Figure 6 FTR3-FTR8 relationship surface
Own Source

Final: Considering two active photoresistors, specifically FTR3 and FTR4, the result of the controller was a rotation in X direction (measurements in the range of [80°, 0°]). The control surface obtained is shown in Figure 7.

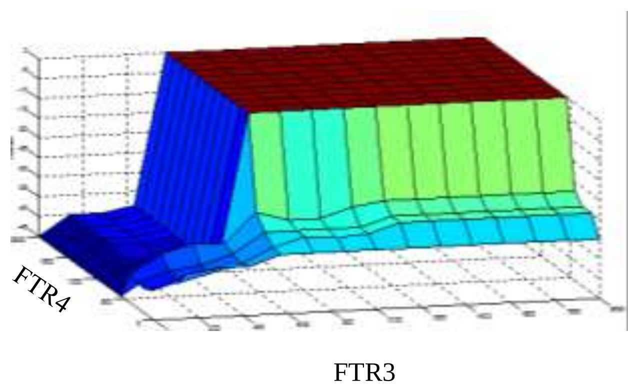

Figure 7 FTR3-FTR4 relationship surface
Own Source

As shown in Figures 5, 6 and 7, there are nonlinear responses, which describes the nature of the fuzzy controller created, without the need to have knowledge of the mathematical model of the system.

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However, as previously indicated, by combining the mathematical model with a fuzzy structure, the response of the system is enhanced.

The results obtained in the validation of the control surfaces (fuzzy control law) are presented below.

Experimental test I: Null resistive values were observed in photoresistances 1 and 2, leaving the rest of the photoresistances at their maximum resistivity (Table 1), implying that the resulting movement is in the negative direction, proving that the assignment of the rules and the defusification method were correct (Figure 8).

output (°)	FTR1 (Ω)	FTR2 (Ω)	FTR3 (Ω)	FTR4 (Ω)	FTR5 (Ω)	FTR6 (Ω)	FTR7 (Ω)	FTR8 (Ω)	FTR9 (Ω)	FTR10 (Ω)
-70.38	0	0	2000	2000	2000	2000	2000	2000	2000	2000

Table 1 Resistive values of the experimental test I
Own Source

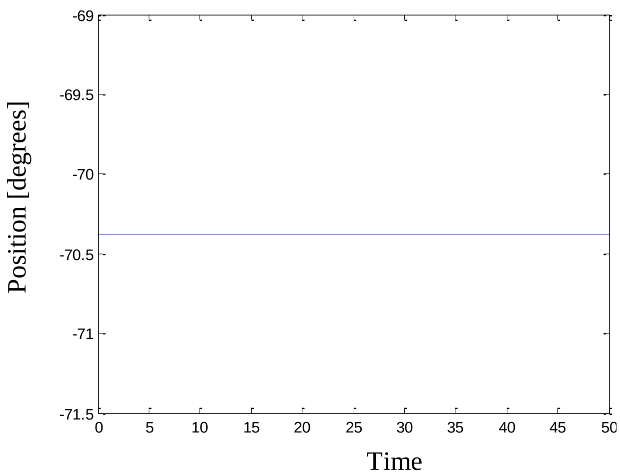

Figure 8 Experimental test I. Motion in east direction (-70.38°)
Own source

Experimental test II: Zero values were assigned to the central photoresistances (3 and 8) with the intention of positioning the receiving surface parallel to the ground, i.e. at 0°, generating an error of -3.34° (Table 2). However, the existence of stability in the system is verified (Figure 9).

output (°)	FTR1 (Ω)	FTR2 (Ω)	FTR3 (Ω)	FTR4 (Ω)	FTR5 (Ω)	FTR6 (Ω)	FTR7 (Ω)	FTR8 (Ω)	FTR9 (Ω)	FTR10 (Ω)
-3.34	2000	2000	0	2000	2000	2000	2000	0	2000	2000

Table 2 Resistive values of the experimental test II
Own Source.

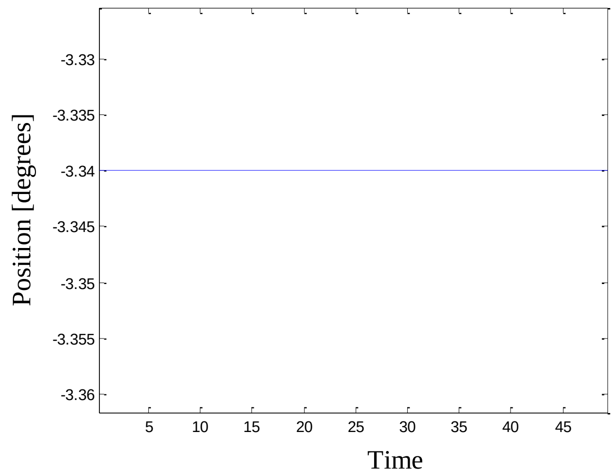

Figure 9 Experimental test II. Positioning parallel to the ground (-3.34°).
Own source

Experimental test III: The assignment of a minimum resistive value in photoresistors 8 and 9, the null value in photoresistor 10 and maximum values of photoresistors 1 (Chaithanakulwat and Cols., 2023) to 7, showed the desired positive positioning at 50°, i.e., a displacement in the westerly direction, obtaining an error of 0.49° (Table 3 and Figure 10).

output (°)	FTR1 (Ω)	FTR2 (Ω)	FTR3 (Ω)	FTR4 (Ω)	FTR5 (Ω)	FTR6 (Ω)	FTR7 (Ω)	FTR8 (Ω)	FTR9 (Ω)	FTR10 (Ω)
49.50	2000	2000	2000	2000	2000	2000	2000	100	200	0

Table 3 Resistive values of experimental test III
Own Source.

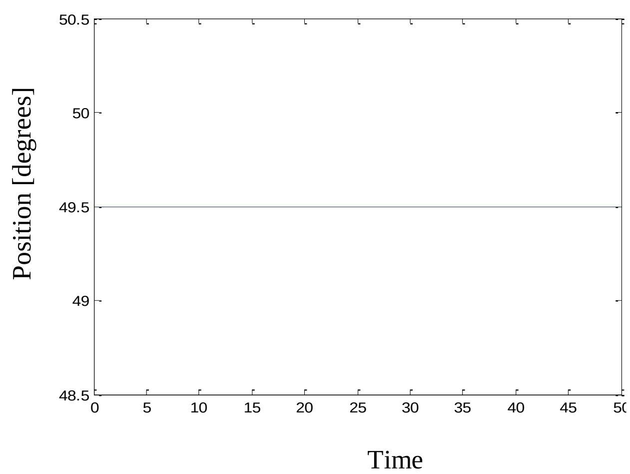

Figure 10 Experimental test III. Movement in westerly direction (49.50°)
Own source

The error values were less than 1° at the extremes (experimental tests I and III), compared to the error generated in experimental test II (3.34°).

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We thank the company MECAS GARAGE represented by Eng. Ubinio Ch. Gómez Sánchez for the support provided in the validation of the inference rules.

Conclusions

The experimental tests considered do not show an error exceeding 4°, which indicates that the proposed fuzzy rules, linguistic terms and defuzzification method are adequate. However, they are susceptible to be improved with the insertion of the mathematical modeling of the mechanical structure. Therefore, it is concluded that the fuzzy control system developed decreases the position error with respect to the incidence of solar radiation, at any instant of time, in the photovoltaic cells and the rotational motion of the Earth.

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Study of the overcurrent protection coordination for radial and ring fed system

Estudio de la coordinación de protección de sobre corriente para sistema radial y en anillo

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Abstract

The distribution systems are normally protected by inverse time overcurrent protection devices. This is due to the natural behavior to tolerate temporal overloading conditions on the distribution lines and its inexpensive cost. Therefore, both radial and ring fed distribution systems are protected using this protection principle. However, the manual time coordination procedure can be tedious and confusing for the new undergraduate protection students. For this reason, this article presents the overcurrent and directional overcurrent protection coordination study considering two parameter settings: time dial and pickup current.

Directional Overcurrent Relay Coordination, Manual Coordination, Radial and Ring Fed System

Resumen

Los sistemas de distribución se protegen normalmente con los dispositivos de protección de sobre corriente de tiempo inverso. Este debido a la naturaleza de poder ofrecer operaciones de sobrecarga temporal en las líneas y por su propiedad económica. Por lo tanto, en sistemas tanto radiales y anillados de distribución, se emplea este principio de protección. Sin embargo, el procedimiento manual de la coordinación por tiempo puede ser un poco tedioso y confuso para los nuevos estudiantes de pregrado de la asignatura de protecciones. Por tal motivo, en este articulo se presenta el estudio de coordinación de protección de sobre corriente y de sobre corriente direccional considerando los dos parámetros de ajustes: la palanca de tiempo dial y la corriente de arranque.

Coordinación Manual, Coordinación de Relevador de Sobre corriente Direccional, Sistema Radial, Sistema en Anillo

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Introduction

To protect electrical power systems, protective devices are employed to perform electrical fault release functions (Uzair, M., Li, L., Eskandari, M., *et al*). Electrical faults can come from nature or human erroneous operations. Then the protective devices have the task to isolate the faulted zone from the electrical network to avoid possible accidents and loss of expensive primary equipment (Blackburn & Domin 2006, section 1.1).

The Over Current Relay (OCR) is mostly employed in distribution systems due to its virtue of tolerating temporary overloads. The OCR is used for single source radial systems and the Directional over Current Relay (DOCR) is used for ring systems with one or more sources. Fault currents are used as an indicator of the location of electrical faults that may flow into or out of the primary or backup protection zone.

Directional over Current Relays (DOCRs) are employed in ring systems to achieve fault direction discrimination and thus adjust the relays (Gers & Holmes 2011, p.125).

Both OCRs and DOCRs need to be adjusted so that they can act as primary protection in their own zone and backup protection in remote zone for distribution lines (Gers & Holmes 2011, p.5-6).

The coordination of RCOs and DOCRs aim to minimize primary operation time (Rojnić, M., Prenc, R., Topić, D. *et al*) and simultaneously offering delayed backup operation time (Blackburn & Domin 2006, section 1.1).

Justification

Overhead lines are the most prone to electrical failures due to natural phenomena due to long distances exposed in the open. Therefore, in order to offer a good electrical supply service while minimizing energy discontinuity and avoiding premature burnout of expensive primary equipment, utilities choose to design and implement protective devices to protect equipment and personnel.

Coordination of RCOs on a radial distribution line can be done by current. However, it is preferred to use time coordination, which can give better results in terms of selectivity of the protections. This is of utmost importance and necessary in ring or meshed networks. Often as the electrical network grows and equipped with higher number of OCRs or DOCRs, the complexity of and time required to execute well the coordination study increases (Gers & Holmes 2011, p.96-97).

Therefore, in this paper aspires to present the study of the coordination problem of radial line OCR and ring line DOCR protections coordination problem for the new undergraduate students of the subject of protections.

Objective

To develop in a manual way and showing clearly the concepts, considerations and steps of OCR and DOCR coordination in radial and ring system.

Mathematical Modeling of the Inverse Time Overcurrent Relay

Overcurrent relays can operate according to IEEE or IEC standard. In the case of this work, it is based on the IEEE C37.112-1996 standard presented in equation 1. Both OCR and DOCR have inverse time characteristic curves. This means that they can be operated in shorter time (fast response) when the magnitude of the fault current is large; and operated in longer time (slow response) when the magnitude of the fault current is small, thus tolerating temporary overloads, or magnetizing current.

$$t = \left[\frac{A}{\left(\frac{I_{sc^{3\emptyset}max}}{I_p} \right)^n - 1} + B \right] * dial \tag{1}$$

Where t is the operating time of the relay, $I_{sc^{3\emptyset}max}$ is the maximum three–phase fault current, I_p is the pickup current of the relay normally set between 1.4 to 2 times the maximum load current, $dial$ is the time lever setting or family of curves, y A, B, n is the IEEE standard constants.

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The IEEE constants defining the conventional inverse time characteristic curves of the overcurrent protection are presented in Table 1. Moderately inverse (MI), very inverse (VI) and extremely inverse (EI). The IEEE curves consider the effect of magnetic saturation of the core relays.

Standard	Curve	A	B	n
IEEE	MI	0.0515	0.114	0.02
	VI	19.61	0.491	2
	EI	28.2	0.1267	2

Table 1 IEEE Standard Constants
Source: IEEE Standard Inverse-Time Characteristic Equations for Overcurrent Relays, IEEE std C37.112-1996

Inverse Time Over Current Protection

The inverse time over current protection (OCR, 51) uses the input signals from the current transformers (CTs) and compares them to the preset value of the inrush current.

If the input current signal exceeds the preset value, then the OCR detects an overcurrent scenario and sends a trip signal to the circuit breaker which will open its contacts to de-energize the protected line. The OCR has no directionality, and is therefore used only in single source radial systems. The OCR operating logic is presented in Figure 1.

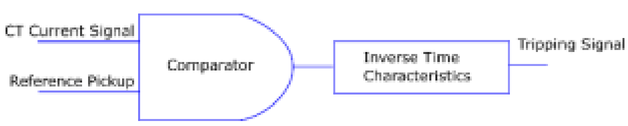

Figure 1 OCR tripping logic
Source: Own Elaboration

Time-reversed directional overcurrent protection (DOCR, 67) are designed to measure the current operating conditions in an electrical circuit and send trip signals to the circuit breakers if an electrical fault is detected. Unlike the OCR, DOCRs have directionality.

Two major measuring instruments are required to perform the DOCR function: current transformer (CT) and potential transformer (PT). Each DOCR is biased with TP voltage signals to be used as reference signal. And when the fault occurs, the phase relationship between voltage and current are analyzed to determine the direction of the fault (Blackburn & Domin 2006).

The DOCR first discriminates whether the fault is located in front of or behind the relay. If the fault is located behind the relay, then no trip signal is sent. However, if the fault is located in front of the relay, a comparison of the fault magnitude and the reference current is made to decide whether or not to send a trip signal to the breaker. The DOCR operating logic is presented in Figure 2.

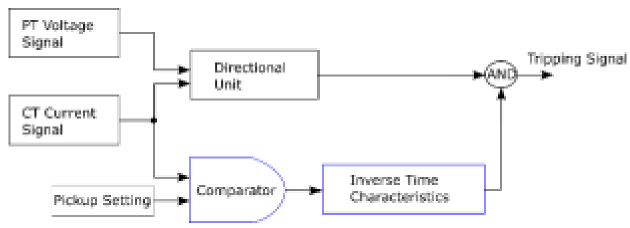

Figure 2 DOCR tripping logic
Source: Own Elaboration

DOCRs only trip when fault events are "in front of" and do not trip for fault events when they are "behind". They are used in radial systems with more than one source, in ringed and meshed systems to discriminate the fault location.

When the current flow is not in the direction of the relay direction, it will not be measured and, therefore, will not trip the relay. In Figure 3, it illustrates that relays A and D detect the load currents of the sources while relays B and C do not detect them because they are in the opposite direction of the current. If a fault occurs on the line located between buses 2 and 3; relays A, C and D will detect the fault and relay B will not detect it because the fault is behind relay B. Similarly, if a fault occurs on the line between buses 1 and 2; relays A, B and D will detect the fault and relay C will not detect the fault because the fault is behind relay C.

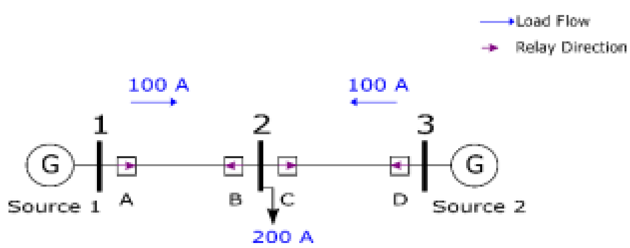

Figure 3 Direction of the DOCRs
Source: Own Elaboration

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Reverse Time Overcurrent Protection Manual Coordination Procedure

The manual procedure for the coordination of OCRs and DOCRs is presented below:

1. Choose one of the IEEE curves, moderately inverse (MI), very inverse (VI) and extremely inverse (EI). Thus to obtain the constants A, B and n. Other standards or from other manufacturers can also be used.

2. Propose the dial time lever for the first over current relay presented in equation 2.

$$dial_{(primary)} = 0.5 \quad (2)$$

It is recommended to use the smallest dial parameter for the first relay in order to minimize the operating time of the relays to be coordinated.

3. Calculate the primary operating time as presented in equation 3.

$$t_{primary} = \left[\frac{A}{\left(\frac{I_{sc3\emptyset max\ primary}}{I_{pickup_{primary}}} \right)^n - 1} + B \right] * dial_{primary} \quad (3)$$

4. Calculate the backup relay operating time as presented in Equation 4.

$$t_{backup} = t_{primary} + CTI \quad (4)$$

The backup relay operating time is calculated by adding a coordination time interval (CTI). This is a delay control of each coordination pair. So, when a primary relay fails to release a fault, the backup can come into operation after the preset CTI time. The CTI is the sum of breaker operating time, electromechanical relay disc overtravel and a safety factor. It can be 0.2 to 0.5 seconds, but is often taken as 0.3 seconds.

5. Calculate the backup relay dial parameter.

$$dial_{backup} = \frac{t_{backup}}{\left[\frac{A}{\left(\frac{I_{sc3\emptyset max\ backup}}{I_{pickup_{backup}}} \right)^n - 1} + B \right]} \quad (5)$$

Repeat steps 3, 4 and 5 continuously until coordination between the different overcurrent relay coordination pairs is established. While steps 1 and 2 are only executed once at the beginning of the coordination process. The coordination of a pair of inverse time relays is illustrated in Figure 4. Based on Figure 3, relay A will provide backup to relay C. This is illustrated with the inverse time characteristic curve in Figure 4.

Where there must be a CTI time between the coordination pair to avoid simultaneous tripping.

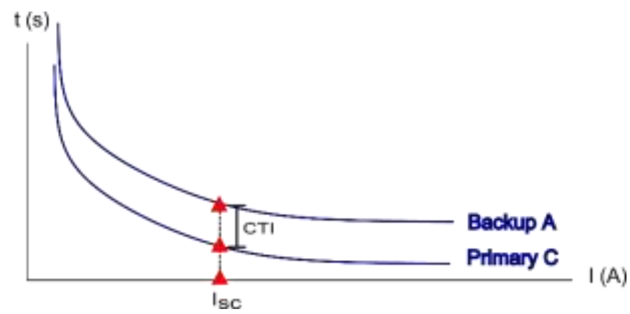

Figure 4 Coordination pair: primary relay and backup
Source: Own Elaboration

It is recommended to use the same curve or in other words the same degree of inversion to avoid possible crossing of curves that leads to loss of coordination. Although using the same curve does not guarantee coordination. When all the OCRs or DOCRs in a system are not coordinated, the process must be started again with a different initial condition (dial time lever).

Study of Manual Coordination of OCRs in a Radio System

Figure 5 shows a single source radial system where OCRs are used. Next, the development of the OCR coordination calculations is presented considering a safety factor k of 1.5 and a CTI of 0.3 seconds.

The steady state load current data as well as the fault currents are presented in Figure 5 and Table 2 and 3.

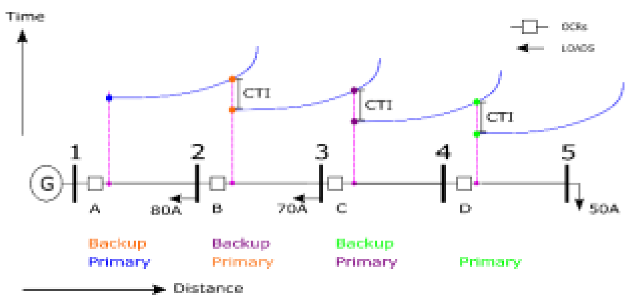

Figure 5 Topology of a radial system with OCRs
Source: Own Elaboration.

Bus	Isc 3ph Primary
1	2000
2	1500
3	1000
4	500

Table 2 Short currents in each bus.
Source: Own Elaboration.

Relay	Isc P	Isc B	Iload	Ipickup
A	2000	1500	80+70+50	300
B	1500	1000	70+50	180
C	1000	500	50	75
D	500	--	50	75

Table 3 Load and short-circuit current data for each relay
Source: Own Elaboration

The coordination study is carried out:

1. Choose the very inverse IEEE curve where has the constants A, B, n are 19.61, 0.491 and 2 respectively according to Table 1.

2. Propose dial for the first relay $dial_{(primary)} = 0.5$.

3. Calculate primary operating time of relay D

$$t_{R_D} = \left[\frac{A}{\left(\frac{I_{sc3\emptyset_{R_D}}}{I_{pickup_{R_D}}}\right)^n - 1} + B\right] * dial_{R_D} =$$

$$\left[\frac{19.61}{\left(\frac{500}{75}\right)^2 - 1} + 0.491\right] * 0.5 = 0.4712$$

4. Calculate operating time for backup relay C

$$t_{R_C} = t_{R_D} + CTI = 0.4712 + 0.3 = 0.7712$$

5. Calculate dial for backup relay C.

$$dial_{R_C} = \frac{t_{R_C}}{\left[\frac{A}{\left(\frac{I_{sc3\emptyset_{R_C}}}{I_{pickup_{R_C}}}\right)^n - 1} + B\right]} = \frac{0.7712}{\left[\frac{19.61}{\left(\frac{500}{75}\right)^2 - 1} + 0.491\right]} =$$

$$0.8273$$

6. Calculate the primary operating time for relay C

$$t_{R_C} = \left[\frac{A}{\left(\frac{I_{sc3\emptyset_{R_C}}}{I_{pickup_{R_C}}}\right)^n - 1} + B\right] * dial_{R_C} =$$

$$\left[\frac{19.61}{\left(\frac{1000}{75}\right)^2 - 1} + 0.491\right] * 0.8273 = 0.4980$$

7. Calculate the operating time of backup relay B

$$t_{R_B} = t_{R_C} + CTI = 0.4980 + 0.3 = 0.7980$$

8. Calculate the dial of the backup relay B

$$dial_{R_B} = \frac{t_{R_B}}{\left[\frac{A}{\left(\frac{I_{sc3\emptyset_{R_B}}}{I_{pickup_{R_B}}}\right)^n - 1} + B\right]} = \frac{0.7980}{\left[\frac{19.61}{\left(\frac{1000}{180}\right)^2 - 1} + 0.491\right]} =$$

$$0.6953$$

9. Calculate the primary operating time of relay B

$$t_{R_B} = \left[\frac{A}{\left(\frac{I_{sc3\emptyset_{R_B}}}{I_{pickup_{R_B}}}\right)^n - 1} + B\right] * dial_{R_B} =$$

$$\left[\frac{19.61}{\left(\frac{1500}{180}\right)^2 - 1} + 0.491\right] * 0.6953 = 0.5406$$

10. Calculate the backup operating time of relay A

$$t_{R_A} = t_{R_B} + CTI = 0.5406 + 0.3 = 0.8406$$

11. Calculate the dial of the backup relay A

$$dial_{R_A} = \frac{t_{R_A}}{\left[\frac{A}{\left(\frac{I_{sc3\emptyset_{R_A}}}{I_{pickup_{R_A}}}\right)^n - 1} + B\right]} = \frac{0.8406}{\left[\frac{19.61}{\left(\frac{1500}{300}\right)^2 - 1} + 0.491\right]} =$$

$$0.6426$$

12. Calculate the primary operating time of relay A.

$$t_{R_A} = \left[\frac{A}{\left(\frac{I_{sc3\emptyset_{R_A}}}{I_{pickup_{R_A}}} \right)^n - 1} + B \right] * dial_{R_A} =$$

$$\left[\frac{19.61}{\left(\frac{2000}{300} \right)^2 - 1} + 0.491 \right] * 0.6426 = 0.6056$$

Relay	tp	tb	dial	Ipickup
A	0.6056	0.8406	0.6426	300
B	0.5406	0.7980	0.6953	180
C	0.4980	0.7712	0.8273	75
D	0.4712	--	0.5000	75

Table 4 Results of primary and backup operation times and the parameters of dial and pickup settings of each relay
Source: Own Elaboration.

DOCR Manual Coordination Study in a Ring System

Figure 6 shows a two-source ring system where DOCRs are used. Next, the development of the DOCR coordination calculations is presented considering a safety factor k of 1.5 and a CTI of 0.3 seconds.

The steady state load current data as well as the fault currents are presented in Figure 6 and Table 5.

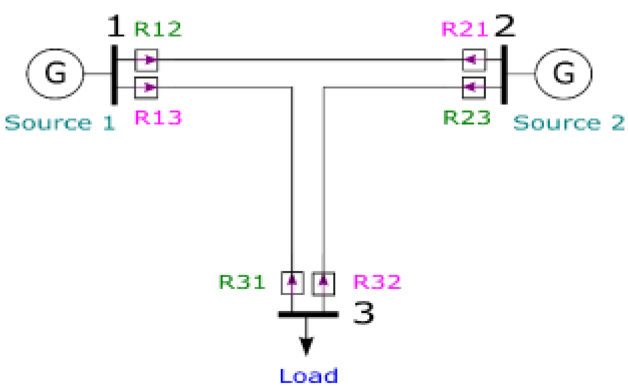

Figure 6 Topology of a ring system with DOCRs
Source: Own Elaboration

Relay	Isc P	Isc B	Iload	Ipickup
1 2	8051	4020	589	883
2 1	8072	4088	589	883
2 3	8515	5716	255	382
3 2	7957	3582	255	382
1 3	8508	7723	826	1239
3 1	5934	3664	826	1239

Table 5 Load and short-circuit current data for each relay.
Source: Own elaboration.

The coordination study is carried out in a clockwise direction:

1. Choose the very inverse IEEE curve where has the constants A, B, n are 19.61, 0.491 and 2 respectively according to Table 1

2. Propose dial for the first relay$dial_{R31} = 0.5$.

3. Calculate primary operating time of the relayR_{31}

$$t_{R_{31}} = \left[\frac{A}{\left(\frac{I_{sc3\emptyset_{R_{31}}}}{I_{pickup_{R_{31}}}} \right)^n - 1} + B \right] * dial_{R_{31}} =$$

$$\left[\frac{19.61}{\left(\frac{5934}{1239} \right)^2 - 1} + 0.491 \right] * 0.5 = 0.6924$$

4. Calculate operation time for backup relay R_{23}

$$t_{R_{23}} = t_{R_{31}} + CTI = 0.6924 + 0.3 = 0.9924$$

5. Calculate the dial for the backup relay R_{23}

$$dial_{R_{23}} = \frac{t_{R_{23}}}{\left[\frac{A}{\left(\frac{I_{sc3\emptyset_{R_{23}}}}{I_{pickup_{R_{23}}}} \right)^n - 1} + B \right]} =$$

$$\frac{0.9924}{\left[\frac{19.61}{\left(\frac{5716}{382} \right)^2 - 1} + 0.491 \right]} = 1.714$$

6. Calculate primary relay operation timeR_{23}

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$$t_{R_{23}} = \left[\frac{A}{\left(\frac{I_{sc3\emptyset_{R_{23}}}}{I_{pickup_{R_{23}}}}\right)^n - 1} + B\right] * dial_{R_{23}} =$$

$$\left[\frac{19.61}{\left(\frac{8515}{382}\right)^2 - 1} + 0.491\right] * 1.714 = 0.9094$$

7. Calculate operating time for backup relayR_{12}

$$t_{R_{12}} = t_{R_{23}} + CTI = 0.9094 + 0.3 = 1.2094$$

8. Calculate dial for backup relay R_{12}

$$dial_{R_{12}} = \frac{t_{R_{12}}}{\left[\frac{A}{\left(\frac{I_{sc3\emptyset_{R_{12}}}}{I_{pickup_{R_{12}}}}\right)^n - 1} + B\right]} =$$

$$\frac{1.2094}{\left[\frac{19.61}{\left(\frac{4020}{883}\right)^2 - 1} + 0.491\right]} = 0.8143$$

9. Calculate the primary relay operating time R_{12}

$$t_{R_{12}} = \left[\frac{A}{\left(\frac{I_{sc3\emptyset_{R_{12}}}}{I_{pickup_{R_{12}}}}\right)^n - 1} + B\right] * dial_{R_{12}} =$$

$$\left[\frac{19.61}{\left(\frac{8051}{883}\right)^2 - 1} + 0.491\right] * 0.8143 = 0.5942$$

10. Calculate the backup relay operation time R_{31}

$$t_{R_{31}} = \left[\frac{A}{\left(\frac{I_{sc3\emptyset_{R_{31}}}}{I_{pickup_{R_{31}}}}\right)^n - 1} + B\right] * dial_{R_{31}} =$$

$$\left[\frac{19.61}{\left(\frac{3664}{1239}\right)^2 - 1} + 0.491\right] * 0.5 = 1.5115$$

We proceed to perform the coordination study in a counterclockwise direction:

1. Choose the very inverse IEEE curve where has the constants A, B, n are 19.61, 0.491 and 2 respectively according to Table 1

2. Propose dial for the first relay$dial_{R21} = 0.8094$.

3. Calculate primary operating time of the relay R_{21}

$$t_{R_{21}} = \left[\frac{A}{\left(\frac{I_{sc3\emptyset_{R_{21}}}}{I_{pickup_{R_{21}}}}\right)^n - 1} + B\right] * dial_{R_{21}} =$$

$$\left[\frac{19.61}{\left(\frac{8072}{883}\right)^2 - 1} + 0.491\right] * 0.8094 = 0.5896$$

4. Calculate operation time for backup relay R_{32}

$$t_{R_{32}} = t_{R_{21}} + CTI = 0.5896 + 0.3 = 0.8896$$

5. Calculate the dial for the backup relay R_{32}

$$dial_{R_{32}} = \frac{t_{R_{32}}}{\left[\frac{A}{\left(\frac{I_{sc3\emptyset_{R_{32}}}}{I_{pickup_{R_{32}}}}\right)^n - 1} + B\right]} =$$

$$\frac{0.8896}{\left[\frac{19.61}{\left(\frac{3582}{382}\right)^2 - 1} + 0.491\right]} = 1.241$$

6. Calculate primary relay operation timeR_{32}

$$t_{R_{32}} = \left[\frac{A}{\left(\frac{I_{sc3\emptyset_{R_{32}}}}{I_{pickup_{R_{32}}}}\right)^n - 1} + B\right] * dial_{R_{32}} =$$

$$\left[\frac{19.61}{\left(\frac{7957}{382}\right)^2 - 1} + 0.491\right] * 1.241 = 0.6655$$

7. Calculate primary relay operation time R_{13}

$$t_{R_{13}} = t_{R_{32}} + CTI = 0.6655 + 0.3 = 0.9655$$

8. Calculate dial for backup relay R_{13}

$$dial_{R_{13}} = \frac{t_{R_{13}}}{\left[\frac{A}{\left(\frac{I_{sc3\emptyset_{R_{13}}}}{I_{pickup_{R_{13}}}}\right)^n - 1} + B\right]} =$$

$$\frac{0.9655}{\left[\frac{19.61}{\left(\frac{7723}{1239}\right)^2 - 1} + 0.491\right]} = 0.9568$$

9. Calculate the primary relay operating time R_{13}

$$t_{R_{13}} = \left[\frac{A}{\left(\frac{I_{sc3\emptyset_{R_{13}}}}{I_{pickup_{R_{13}}}} \right)^n - 1} + B \right] * dial_{R_{13}} =$$

$$\left[\frac{19.61}{\left(\frac{8508}{1239} \right)^2 - 1} + 0.491 \right] * 0.9568 = 0.8763$$

10. Calculate backup relay operating time R_{21}

$$t_{R_{21}} = \left[\frac{A}{\left(\frac{I_{sc3\emptyset_{R_{21}}}}{I_{pickup_{R_{21}}}} \right)^n - 1} + B \right] * dial_{R_{21}} =$$

$$\left[\frac{19.61}{\left(\frac{4088}{883} \right)^2 - 1} + 0.491 \right] * 0.8094 = 1.1742$$

Realy	tp	tb	dial
1 2	0.5942	1.2094	0.8143
2 1	0.5896	1.1742	0.8094
2 3	0.9094	0.9924	1.7140
3 2	0.6655	0.8896	1.2410
1 3	0.8763	0.9655	0.9568
3 1	0.6924	1.5115	0.5000

Table 6 Results of primary and backup operating times and the parameters of each relay's dial settings.
Source: Own Elaboration.

Coordination Couples	tp	tb	CTI
[1 2] [2 3]	0.9094	1.2094	0.3000
[2 1] [1 3]	0.8763	1.1742	0.3000
[2 3] [3 1]	0.6924	0.9924	0.3000
[3 2] [2 1]	0.5896	0.8896	0.3000
[1 3] [3 2]	0.6655	0.9655	0.3000
[3 1] [1 2]	0.5942	1.5115	0.9173

Table 7 Results of primary and backup operation times and CTIs of each coordination pair
Source: Own Elaboration.

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Conclusions

The study of overcurrent protection coordination is of great importance in radial or ring overhead line systems. Without proper setting or coordination of OCRs and/or DOCRs, it can lead to possible damage to electrical substation personnel and primary equipment in a power failure scenario. Therefore, the step-by-step study and methodology of OCRs and DOCRs coordination is presented in this paper.

In a radial system, the coordination process is started from the farthest relay from the power source, proposing a minimum dial setting. And eventually the last OCR that is close to the source is coordinated.

In a ring system, a starting point is chosen and coordinates the system. But if the DOCRs are not coordinated by the time you close the ring, then you will have to choose another starting point and repeat the coordination again. Therefore, repeat until the ring system is coordinated.

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* Correspondence to Author (example@example.org)
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Text in Times New Roman No.12, single space.

General explanation of the subject and explain why it is important.

What is your added value with respect to other techniques?

Clearly focus each of its features

Clearly explain the problem to be solved and the central hypothesis.

Explanation of sections Article.

Development of headings and subheadings of the article with subsequent numbers

[Title No.12 in Times New Roman, single spaced and bold]

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In the article content any graphic, table and figure should be editable formats that can change size, type and number of letter, for the purposes of edition, these must be high quality, not pixelated and should be noticeable even reducing image scale.

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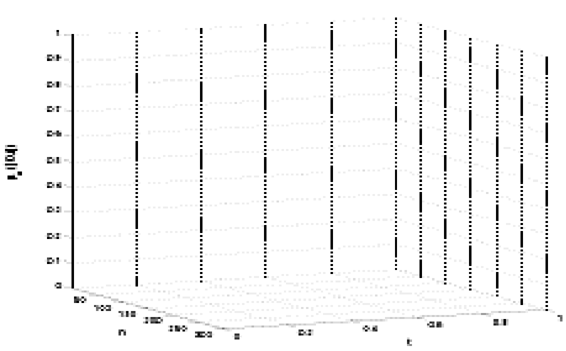

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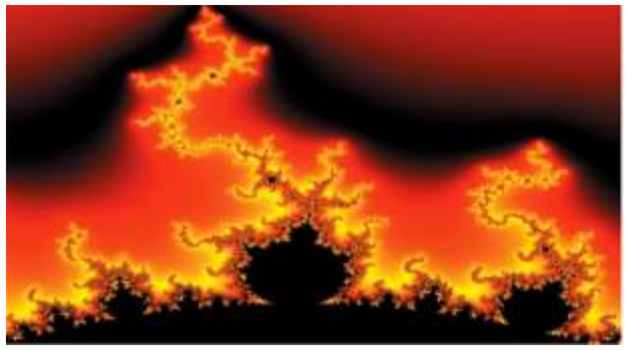

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$$Y_{ij} = \alpha + \sum_{h=1}^{r} \beta_h X_{hij} + u_j + e_{ij} \qquad (1)$$

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Methodology

Develop give the meaning of the variables in linear writing and important is the comparison of the used criteria.

Results

The results shall be by section of the article.

Annexes

Tables and adequate sources

Thanks

Indicate if they were financed by any institution, University or company.

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Conclusions

Explain clearly the results and possibilities of improvement.

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