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Presentation of the content

In the first article we present, *Total harmonic distortion optimization in a seven level multilevel inverter by the random search heuristic algorithm* by GÓMEZ-ROSAS, Ana María, TORRES-CRUZ, Nicolas, JOERS-DELGADO, Carlos, PEÑA and DELGADO, Adrián Fermín, with adscription in the Universidad Tecnológica de Altamira and Instituto Tecnológico de Ciudad Madero, in the next article we present, *Prediction of thermal infrared radiation using an artificial neural network applied to the projection and design of processes in renewable energies* by VALENCIA-TOBIAS Francia Paulette, MERINO-TREVIÑO, Marco Antonio, GARCIA-PÉREZ Fátima Fernanda and CENTENO-SIERRA, Mariana Soledad, with adscription in the Universidad Tecnológica de Altamira, in the next article we present, *Processing and recognition of EMG signals through CNN networks for the control of electric vehicles* by LOPEZ-RODRIGUEZ, Pedro, MONTIEL-RODRIGUEZ, Martin, SAMANO-FLORES, Yosafat Jetsemani and MANDUJANO-NAVA, Arturo, with adscription in the Universidad Politécnica de Guanajuato, in the last article we present, *Unsupervised learning model to determine a classification based on the cost-benefit ratio of school notebooks in Mexico* by URUETA-HINOJOSA, Daniel Edahi, GALVÁN-ZAVALA, Karina, LAVÍN-DELGADO, Jorge Enrique and SUÁREZ-ESCOBAR Jorge Armando, with adscription in the Universidad Politécnica del Estado de Guerrero and Universidad de Guanajuato.

Content

Article **ECORFAN Journal- Taiwan**
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Total harmonic distortion optimization in a seven level multilevel inverter by the random search heuristic algorithm

Optimización de la distorsión armónica total en un inversor multinivel de siete niveles empleando un algoritmo heurístico de búsqueda aleatoria

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Abstract

In this article, the random search heuristic optimization algorithm is proposed to guarantee that the voltage synthesized by a seven-level multilevel inverter contains the lowest possible total harmonic distortion. The algorithm in this work is presented as an alternative, simple, and easy-to-implement method for solving a set of transcendental mathematical equations of multilevel inverters. The obtained results demonstrate the algorithm's capability to solve the mathematical formulation that minimizes the total harmonic distortion. It is important to highlight that the algorithm was implemented in Matlab®, and the obtained results were validated in a simulation conducted in Simulink®. Equally and not less important, the results were physically implemented in a laboratory prototype of three integrated circuits with H-bridges containing insulated gate bipolar transistors.

Algorithm, Optimization, Multilevel-Inverter, Total Harmonic Distortion

Resumen

En este artículo se propone el uso de un algoritmo de optimización heurístico de búsqueda aleatoria para que permita garantizar que la tensión sintetizada por un inversor multinivel de siete niveles contenga la menor distorsión armónica total posible. El algoritmo expuesto en este trabajo se propone como un método alterno, simple y de fácil implementación para la solución de ecuaciones matemáticas trascendentales de un inversor multinivel. Los resultados expuestos demuestran el correcto funcionamiento del algoritmo al minimizar la forma distorsión armónica total de la onda de salida. Es importante destacar que el algoritmo fue implementado en el software Matlab® y los resultados obtenidos fueron validados por medio de simulación en el software Simulink®. De igual y no menos importante, los resultados fueron implementados de manera física en un prototipo de laboratorio que consta de tres circuitos integrados con puentes H, los cuales contienen transistores bipolares de compuerta aislada.

Algoritmo, Optimización, Inversor Multinivel, Distorción Armónica Total

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Introduction

Nowadays, there is an increase in the use of alternative or renewable energy sources such as photovoltaic cells, wind generators, fuel cells, among others in the industrial, commercial and residential sectors (Vaiaso & Jack, 2021). This is because these energy sources offer direct benefits for the environment and their cost has been reduced thanks to current technological advances. While such energy sources are becoming more widely used and more studied every day, the use of various specialised electronic circuits capable of synthesising a voltage and current that meets the guidelines stipulated by the electrical or electronic products that are to be used with renewable energy sources is indispensable.

Among the most common electronic circuits used in the area of alternating energies are the DC-DC converters, also known as switched-mode power supplies, and the DC-AC converters, also known as inverters, the latter being the one studied in this article.

Inverters are circuits capable of synthesising a voltage and current in the form of a modulated alternating wave, with variable amplitude and frequency, from direct current sources. This makes them indispensable in applications related to electricity generation with renewable energy sources (Colak et al., 2011).

Within the literature, inverters can be classified into two types, constant voltage source inverters and constant current source inverters, the former being the most widely used due to its better performance and practicality (El-Hosainy et al., 2017). This paper focuses on the use of a constant voltage source inverter. Similarly, constant voltage source inverters can be subclassified into two-level, three-level and multilevel inverters. The following figures show the waveforms that can be synthesised by the above-mentioned inverters.

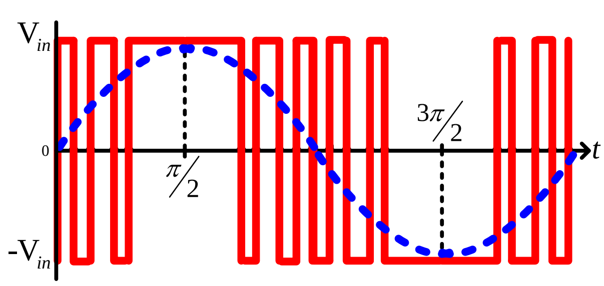

Figure 1 Two-level alternating voltage

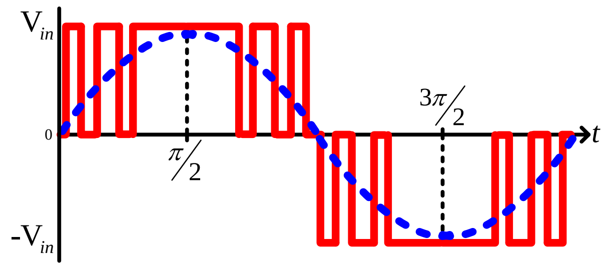

Figure 2 Three-level alternating voltage

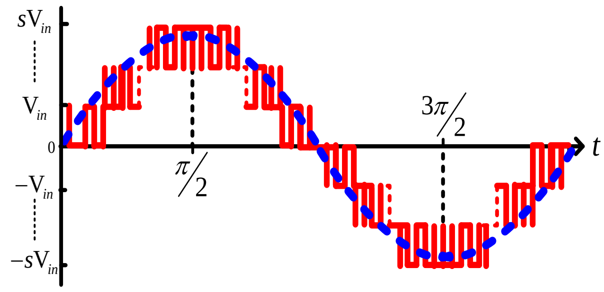

Figure 3 Multilevel AC voltage

Similarly, Figures 4, 5 and 6 show the general schematics of constant voltage source inverter types, where switch "A" is usually a power switching device such as a MOSFET or IGBT.

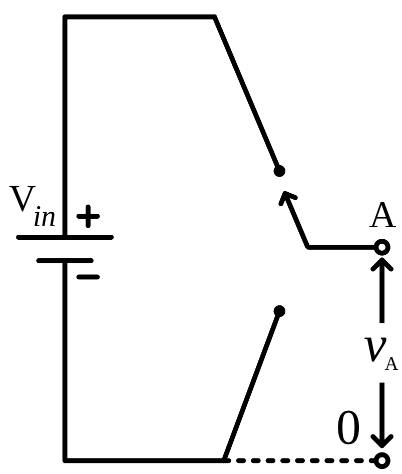

Figure 4 Two-level inverter

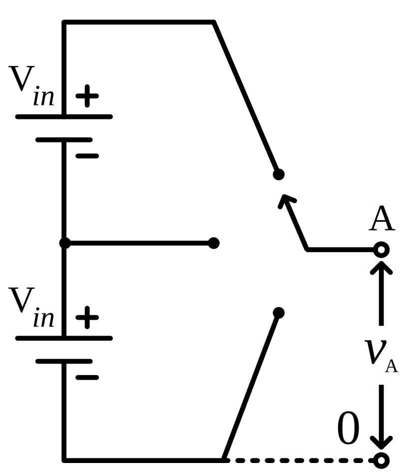

Figure 5 Inversor de tres niveles

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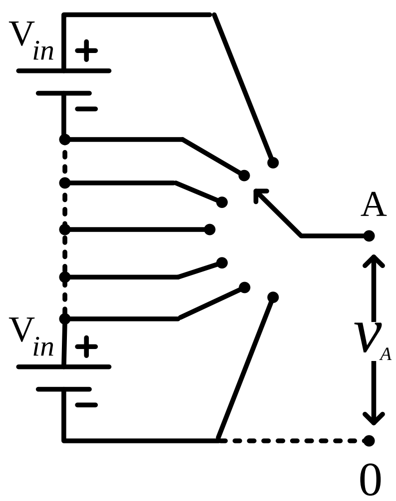


Figure 6 Multilevel AC voltage

Since its inception, multiple studies have reported the multilevel inverter as the best alternative to conventional two- and three-level inverters. This is mainly because they are able to supply higher power levels with lower cost switching devices, in addition, the synthesised voltage has a lower harmonic content (Reddy & Narayana, 2020).

Modulation techniques

Modulation techniques are used in inverters to control the on and off times of the switching devices that compose them, being these mechanisms that allow to give particular characteristics to the voltage synthesised by the inverter. Among its most important features is the possibility of manipulating the amplitude, phase and frequency (Vijeh et al., 2019). Globally, modulation techniques can be classified into high and low switching frequency and the use of these is subject to the type of application. Based on the above, this paper will focus on the use of a low switching frequency modulation technique.

Low switching frequency modulation techniques are techniques designed with the purpose of making inverters achieve the best possible efficiency and prolonging the lifetime of the switching devices. These techniques are used in applications demanding very high power levels.

Harmonic distortion

Harmonics are defined as sine components of a periodic wave called the fundamental that have a frequency corresponding to an integer multiple of the fundamental frequency wave (Reddy & Narayana, 2020). Measuring the harmonic content of the voltage waveform synthesised by inverters is a fundamental part of determining their performance (Aguila-León et al., 2023) (Khan et al., 2023). Nowadays, norms and standards limit the harmonic content of the voltage and current synthesised by inverters, so ensuring the lowest possible harmonic content is necessary.

Total Harmonic Distortion (THD) is a parameter that quantifies the deviation between the waveform of a sinusoidal signal against any other type of periodic signal (usually voltage and/or current). Official Mexican standards such as CFE L-000045 recommend the quantification of this parameter up to the fiftieth harmonic order and is given by the following equation.

$$\mathrm{THD_V} = \frac{\mathrm{V_{RMS}}}{\mathrm{V_{1RMS}}} = \frac{\sqrt{\sum_{\mathrm{h}=2}^{50} V_h^2}}{V_1} 100\% \tag{1}$$

Where, the magnitude of the fundamental component (Aboadla et al., 2016) is given by V1RMS, the magnitude of the h-th harmonic component will be V_h and the order of each harmonic will be h. While VRMS is the rms value of the voltage function synthesised by the inverter.

Optimisation algorithms

Optimisation algorithms (Houssein et al., 2021) are numerical methods, usually heuristics, capable of finding optimal values of a specific parameter in a problem that can be expressed by means of a mathematical function. This value or values minimise or maximise the objective function. It is important to note that the search for those optimal values is performed by means of population dynamics within an n-dimensional search space. This paper presents the use of the random search heuristic algorithm as an option to determine the firing angles of the semiconductor devices of a multilevel inverter to obtain its ladder output voltage.

The heuristic random search algorithm has the fundamental purpose of solving optimisation problems in a simple way. The dynamics of this algorithm is based on the iterative process of a population of elements, PS, in which each interaction starts from a feasible solution whose neighbourhood is analysed to subsequently locate better solutions. If the solution located by each interaction, j, improves the previous one, j-1, this will be maintained as the best global solution, Gb, and will be used in the next interaction, j+1. On the other hand, the mechanism used in the first interaction for the first possible solutions can be constructed randomly within a search window that follows constraints imposed by the problem to be solved. Gb1

THD minimisation at a seven level output voltage

A multilevel inverter is capable of generating an alternating waveform voltage varying in amplitude and frequency from multiple constant voltage levels. This voltage can come from renewable energy sources such as photovoltaic modules. Several works report that the voltage generated by multilevel inverters has a harmonic content that is inversely proportional to the number of levels. This work concentrates only on the case of a seven-level single-phase inverter. The following figure shows the possible voltage waveform to be synthesised by a 7-level multilevel inverter.

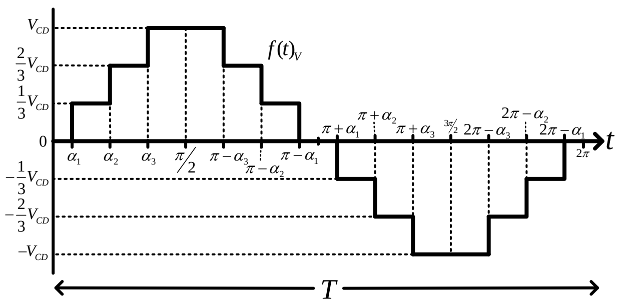


Figure 7 Seven-level alternating voltage

It is important to note that the synthesised voltage considers the levels of the voltage sources as constant and of equal magnitude. Because of this, and considering the odd symmetry in the waveform shown, it can be expressed in Fourier series as (Ajami et al., 2013):

$$f(t)_V = \frac{4\mathrm{V_{CD}}}{3\pi}\sum_{\mathrm{n=1}}^{\infty} V_h^2\, [\cos(n\alpha_1) + \cos(n\alpha_2) + \cos(n\alpha_3)]\, \frac{\sin(n\omega_0 t)}{n} \quad (2)$$

Similarly, it is possible to calculate its r.m.s. value with the following equation.

$$f(t)_{VRMS} = \frac{\mathrm{V_{CD}}}{3}\sqrt{9 - \frac{\alpha_1 + 3\alpha_2 + 5\alpha_3}{90}} \quad (3)$$

Where $\alpha_1 < \alpha_2 < \alpha_3 < 90°$ determine the switching on and off of the switching devices.

On the other hand, from equation (2) we can calculate its fundamental component, when *n=1*, with:

$$f(t)_{V1} = \frac{4\mathrm{V_{CD}}}{3\pi}\sum_{\mathrm{n=1}}^{\infty} V_h^2\, [\cos(n\alpha_1) + \cos(n\alpha_2) + \cos(n\alpha_3)]\, \sin(\omega_0 t) \quad (4)$$

Where its r.m.s. value would be given by:

$$f(t)_{V1RMS} = \frac{2\sqrt{2}\mathrm{V_{CD}}}{3\pi}[\cos(\alpha_1) + \cos(\alpha_2) + \cos(\alpha_3)] \quad (5)$$

Similarly, the THD can be calculated with:

$$THD_V = \frac{\sqrt{f(t)_{VRMS}^2 - f(t)_{V1RMS}^2}}{f(t)_{V1RMS}^2}100\% \quad (6)$$

Substituting (3) and (5) into (6) we can obtain that the THD of such a waveform can be calculated with:

$$THD_V = \frac{25\sqrt{2}\sqrt{9\pi^2 - A - B - C}}{D}100\% \quad (7)$$

Where:

$$A = \pi^2\left(\frac{\alpha_1 + 3\alpha_2 + 5\alpha_3}{90}\right)$$

$$B = 8[\cos(\alpha_1)^2 + \cos(\alpha_2)^2 + \cos(\alpha_3)^2]$$

$$C = 16[\cos(\alpha_1)\cos(\alpha_2) + \cos(\alpha_1)\cos(\alpha_3) + \cos(\alpha_2)\cos(\alpha_3)]$$

$$D = \cos(\alpha_1) + \cos(\alpha_2) + \cos(\alpha_3)$$

Equation 7 will be used as the objective function to be minimised by the algorithm proposed in this article.

Programming methodology of the algorithm

Because the proposed algorithm uses the population dynamics of a set of elements, calculating the position and velocity of the switching angle values is necessary.

For this purpose, the position and velocity of the vectors of each element, ith and the interaction, jth can be calculated with the following equations:

$$\alpha_i^j = \left(\alpha_i^j, \alpha_{i2}^j, \alpha_{i3}^j\right) \tag{8}$$

$$\Delta\alpha_i^j = \left(\Delta\alpha_i^j, \Delta\alpha_{i2}^j, \Delta\alpha_{i3}^j\right) \tag{9}$$

Where, αij represents the possible optimal values to be used for switching the multilevel inverter switching devices, Δαij, is the velocity and determines the change of the position of each αi. The objective function given by equation (7), evaluates the capabilities for each αij fundamental process to recalculate future positions, αij+1 and velocities, Δαij+1. The following equations show how to calculate these parameters:

$$\alpha_i^{j+1} = G_b + \Delta\alpha_i^j \tag{10}$$

$$\Delta\alpha_i^{j+1} = \left\| \operatorname{ran}\left(\frac{1}{i}\right) - \frac{P_s}{i} \right\| \tag{11}$$

The following figure shows the scheme followed for the programming of the proposed algorithm.

Algoritmo heurístico de búsqueda aleatoria

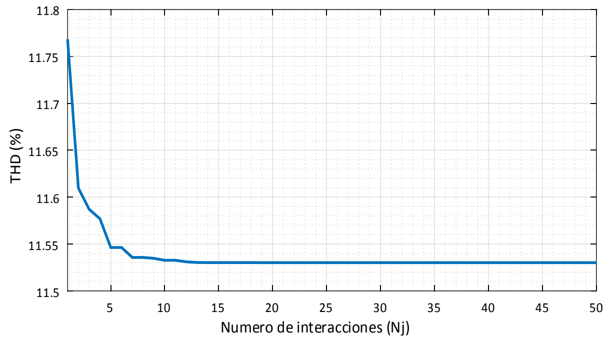
Procedimiento
1: Datos de entrada: P_S, and N_j.
2: $\alpha \leftarrow$ Soluciones iniciales {rand(π/2)}
Aquí asumimos que $\alpha=<\alpha_1, \alpha_2, \alpha_3>$
3: Sort(α)
4: Evaluación de la función objetivo
5: Selección del mejor valor $G_{b(0)}$
6: **for**($j=1$; $j<N_j$; j++) **do**
7: Calcular Δx_i^{j+1}
8: Calcular x_i^{j+1}
9: Evaluar la función objetivo
10: Selección de $G_{b(j)}$
11: $j = j+1$
12: **end for**

Figure 8 Programming procedure

Results

Following the methodology proposed in this article and evaluating the objective function with an initial population "Np" as well as a number of iterations "Nj" of 50, it was possible to minimise the objective function to a minimum value of minimum THDV=11.5303, with the switching angles α1=8.8827, α2=27.5967 and α3=50.5412.

The following graph shows the behaviour of the objective function.



Graph 1 Dynamics of the objective function

It can be observed that with the use of the proposed algorithm the objective function converges to a value of 11.55 from Nj=10. However, the algorithm from this interaction continues to minimise the function until it remains stable.

Based on the switching angles found, the following system implementation in the multilevel inverter was chosen.

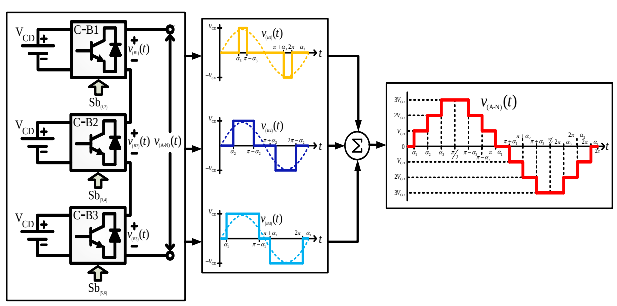


Figure 9 Implementation scheme

Figure 10 samples the seven-level waveform obtained through simulation from the scheme shown using the previously calculated optimisation angles.

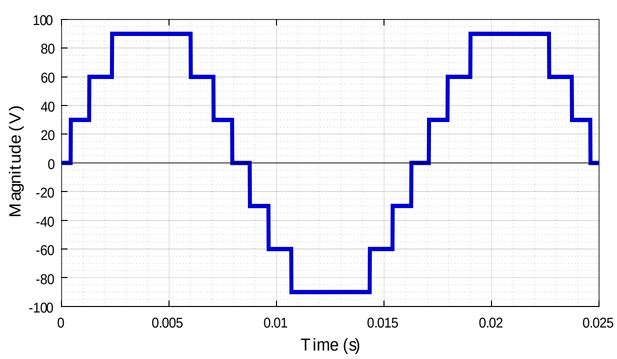


Figure 10 Seven-level waveform

Similarly, Figure 11 shows the harmonic spectrum corresponding to the staircase waveform previously shown in Figure 9. It is observed that the difference between the THDV obtained during optimisation and that determined through the waveform has a difference of about 1.0803 in the percentage of total harmonic distortion.

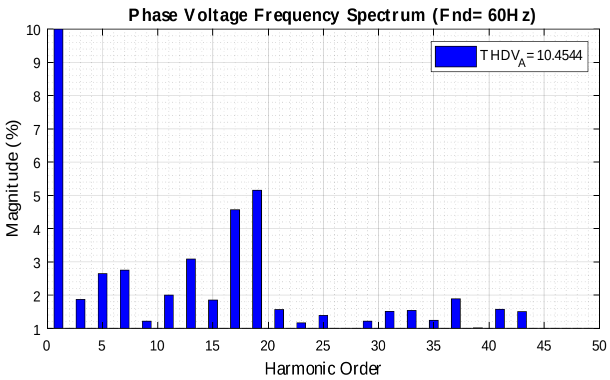


Figure 11 Harmonic spectrum

Conclusion

As could be demonstrated by the results obtained, the objective function proposed in this article was successfully minimised. The optimal switching angles were found by means of a simple and easy to implement algorithm. These results were validated by simulation through a spectral analysis on the voltage waveform obtained by a seven-level multilevel inverter. Based on the above, the use of heuristic random search algorithms for the solution of the total harmonic distortion minimisation problem in 7-level multilevel inverters is validated.

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Prediction of thermal infrared radiation using an artificial neural network applied to the projection and design of processes in renewable energies

Predicción de radiación infrarroja térmica, utilizando una red neuronal artificial, aplicada a proyección y diseño de procesos en energías renovables

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Abstract

This work aims to predict thermal infrared radiation in geographical areas where the necessary measurement devices are not available, through the design of an artificial neural network (RNA). The RNA uses the following variables as input data: specific humidity, relative humidity, ambient temperature, wind speed, and atmospheric pressure, it is important to mention that the sample of space of time is from, (1990 - 2019), they are data from Mexico City, as it is a metropolis with an extensive air quality database, which are obtained from two online tools developed by the National Aeronautics and Space Administration (NASA). In addition, thermal infrared radiation data from NASA are included, to validate the prediction made by the algorithm. Matlab was used to implement RNA, a multiplatform software that offers an integrated development environment with its own programming language. It is recognized for its computational ability and is considered a suitable tool for this purpose.

Irradiance thermal infrared, Artificial Neural Network, Prediction

Resumen

El propósito de este trabajo es llevar a cabo una predicción de la radiación infrarroja térmica en zonas geográficas en donde no se cuenta con los dispositivos de medición necesarios, esto a través del diseño de una red neuronal artificial (RNA). La RNA utiliza como datos de entrada las siguientes variables: humedad específica, la humedad relativa, temperatura ambiente, velocidad del viento y presión atmosférica, es importante mencionar que la muestra de espacio de tiempo es de, (1990 – 2019), son datos de la Ciudad de México, ya que es una metrópolis con una extensa base de datos de calidad del aire, los cuales se obtienen de dos herramientas en línea desarrolladas por la Administración Nacional de Aeronáutica y el Espacio (NASA; por sus siglas en inglés). Además, se incluyen datos de radiación infrarroja térmica de NASA, con la finalidad de validar la predicción realizada por el algoritmo. Para la implementación de la RNA se empleó Matlab, un software multiplataforma que ofrece un entorno de desarrollo integrado junto con un lenguaje de programación propio. Es reconocido por su capacidad en el cómputo y se considera una herramienta adecuada para este propósito.

Radiación infrarroja térmica, Redes Neuronales Artificiales, Predicción

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Introduction

Machine learning models known as neural networks have been inspired by the structure and function of the human brain. These networks consist of a series of interconnected neurons that process and transform input information to generate output. Synaptic weights determine the direction and strength of the neural connections, and adjust as the network receives more inputs.

In the context of the development of ANN for solar irradiance prediction, this approach is now essential. Various applications, such as meteorology, require accurate data, and longwave downward irradiance is closely related to various weather parameters, such as temperature, humidity and wind speed.

By applying neural networks in this field, we seek to take advantage of their ability to capture complex, non-linear relationships between input variables and solar irradiance. By analysing the collected data and implementing learning algorithms, ANN can learn and generalise patterns from the available records. This allows for more accurate and reliable predictions of solar irradiance based on weather conditions and other relevant factors.

The present research focuses on the use of neural networks, analysing the development of ANN for longwave downward irradiance prediction, which is inspired by the functioning of the human brain. This approach is essential for more accurate and relevant results in applications such as meteorology, where data accuracy is crucial.

The ability of neural networks to capture complex relationships and their adaptability as more records are incorporated make them a powerful tool for improving the prediction of solar irradiance and its relationship with weather parameters.

Several algorithms were developed: to calculate the thermal infrared radiation produced in the atmosphere in order to see the behaviour in different environments (INEGYCEI, n.d.).

1. Background

1.1. Artificial Neural Network

Artificial neural network (ANN) is a machine learning approach inspired by biological processes in the human brain (Aitkenhead-Peterson et al., 2007) (Hameed et al., 2019) The basic architecture of an ANN consists of processing units called neurons, which are interconnected by appropriate links. Each individual neuron includes weight activation functions, summation points and outputs, as illustrated in Figure 1.

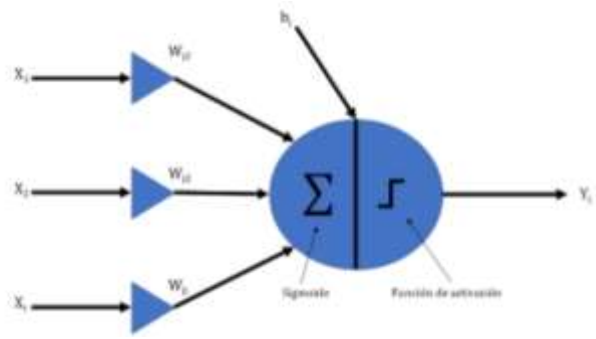

Figure 1 Simplified model of an artificial neuron
Source: Own Elaboration

In the operation of an ANN, the input data, represented by x1, ..., xi, is weighted by input weights wj1, ..., wji, and a bias bj is added before the neuron generates an output yj.

A key aspect of ANNs is their supervised learning capability, using input and output data sets. During the learning process, the network is adjusted to reach the same reference or set point that is set by a supervisor. Training is repeated until the difference between the ANN output and the supervisor's benchmark is within acceptable ranges (Aitkenhead-Peterson et al., 2007).

The most commonly used structure is the feedforward network, which consists of individual neurons organised in layers and connected by weighted connections. An example of a three-layer ANN is shown in Figure 2. (David J. Lvingstone, 2009)

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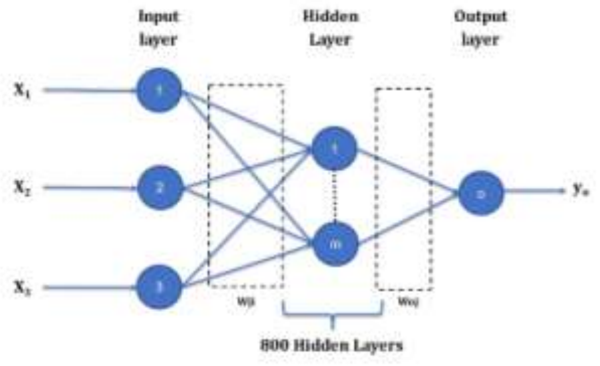


Figure 2 3-layer Artificial Neural Network
Source: Own Elaboration

The backpropagation algorithm is the most popular training method for feedforward networks and is based on supervised learning. The desired input and output data patterns are obtained through simulation studies of the mathematical model of the neuron.

1.2. Thermal infrared radiation in general

The irradiance of the sky surface, also known as thermal infrared radiation, can be calculated using the Stefan-Boltzmann law and considering various atmospheric factors. Here is a general formula for calculating this irradiance (Velasco Ramón Javier, 2019).

$$I = \varepsilon \sigma A T^4 \quad (1)$$

Where:

I is the irradiance of the sky surface (*W/m²*).
ε is the effective emissivity of the sky.
A is the surface area of the emitter
σ is the Stefan-Boltzmann constant ($5.67\, x\, 10^{-8} W/m^2 \cdot K^4$)
T is the effective sky temperature in Kelvin (K).

1.3. Thermal infrared radiation in the atmosphere

The calculation of atmospheric thermal infrared radiation can be complex and requires consideration of multiple atmospheric factors and radiative properties. Two common methods for calculating atmospheric thermal infrared radiation are listed below:

Use of radiative measurements and atmospheric profiles: This approach uses thermal infrared radiation measurements and atmospheric profiles, such as air temperature, humidity and gas concentration, to calculate atmospheric thermal infrared radiation.

Techniques such as atmospheric spectroscopy and spectral radiation analysis are used to obtain information on the radiative properties of the atmosphere in the thermal infrared range.

2. Radiative transfer model-based method

This method uses transfer models to estimate atmospheric thermal infrared radiation. These models take into account factors such as air temperature, greenhouse gas concentration and atmospheric humidity. The best known model is the broadband or grey body model.

Both methods require detailed knowledge of atmospheric parameters and may involve the use of computer models or specialised measurements. In addition, the accuracy of the calculations will depend on the availability and quality of the atmospheric data used. For this purpose, the radiative transfer model is used to calculate the atmospheric thermal infrared radiation considering greenhouse gases such as: Carbon dioxide (CO_2), Methane (CH4), Nitrous oxide (N_2O), other variables immersed in the calculation are: temperature and humidity:

To relate the thermal infrared radiation equation to atmospheric pressure, temperature, specific humidity, relative humidity and wind speed, it is necessary to understand that each of these factors affects the parameters of this.

3. Emissivity

It is a constant physical property that has the ability to emit energy in the form of thermal radiation from a surface, during different climatic conditions. Emissivity is present on most of the Earth's natural surfaces ranging from 0.6 to 1.0, but surfaces with emissivities below 0.85 are usually restricted to deserts and semi-arid areas. Vegetation, water and ice have high emissivities above 0.95 in the thermal infrared wavelength range. However, it is necessary to consider that specific atmospheric measurements and advanced radiative models are needed to obtain accurate values.

In the case of Mexico City (CDMX), the emissivity of its urban surface, its level differs significantly. A study published in the International Journal of Remote Sensing used satellite imagery to calculate the emissivity of the city's urban surface.

Where it was estimated to have an emissivity that fluctuates according to texture and material type, ranging from 0.88 to 0.95.(Saleh et al., 2018).

Certain NASA sensors, such as the Advanced Spaceborne Thermal Emission and Reflectance Radiometer (ASTER), Moderate Resolution Imaging Spectroradiometer (MODIS) and Atmospheric Infrared Sounding System (AIRS) (U.S./Japan ASTER Science Team, 2014) are able to detect changes in emissivity.

4. Stefan-Boltzmann constant

The Stefan-Boltzmann constant is a fundamental constant in physics used to relate the temperature of an object to the total amount of thermal radiation it emits. Its value is denoted by the Greek letter sigma (σ) and its approximate value is 5.67 x 10^-8 watts per square metre per kelvin to the fourth power (W/m^2-K^4).

In the context of infrared thermal radiation, the Stefan-Boltzmann constant is used to calculate the power radiated by an object as a function of its temperature and emissivity. Emissivity is a property describing the ability of an object to emit thermal radiation.

The basic formula using the Stefan-Boltzmann constant is:

$$Radiated\ power = \sigma * emissivity * Area * Temperature^{4} \quad (2)$$

Where:

σ is the Stefan-Boltzmann constant.
Emissivity is the emissivity of the object (a value between 0 and 1 indicating how efficiently it emits radiation).
Area is the surface area of the object.
Temperature is the temperature of the object in Kelvin (K).

This formula allows us to calculate the power radiated by an object as a function of its temperature and emissivity. The higher the temperature of the object, the higher the radiated power. Also, a higher emissivity means that the object will emit more thermal radiation.

The Stefan-Boltzmann constant is essential in the estimation of thermal energy fluxes and in the characterisation of celestial bodies, as it allows us to understand and quantify the amount of thermal radiation emitted as a function of the temperature and emissivity properties of objects.

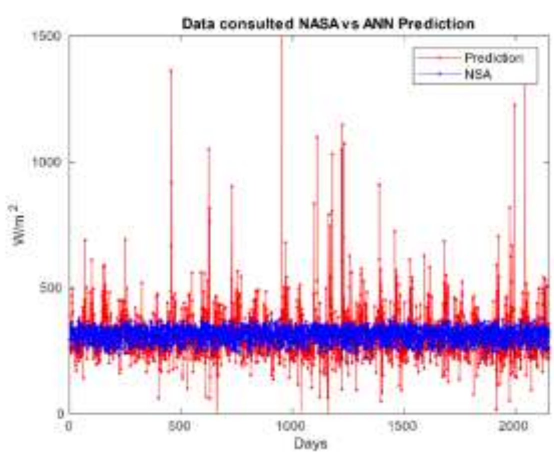
5. Description of the method

During the development of the present project, different methodologies were implemented using the multiplatform Matlab software. In the first instance, a detailed search was carried out on greenhouse gases, obtained from the National Inventory of Emissions of Greenhouse Gases and Compounds (INEGYCEI), period from 1990 to 2019.

Therefore, a script was created to convert the units from gigagrams (Gg) to parts per million (ppm), in order to calculate the concentrations of each gas, through atmospheric parameters such as pressure, temperature and humidity, using the atmospheric thermal infrared radiation formula, which associates emissions with the total volume of the atmosphere. The result obtained is the atmospheric thermal irradiation in W/m^2.

However, a calculation was also developed using the Stefan Boltzman's Law formula to determine the thermal infrared radiation given by the variables of emissivity, temperature, area and distance, in the case of Mexico City, there is an emissivity of 0.95.

6. Results



Graph 1 NASA vs ANN Prediction
Source: Own Elaboration

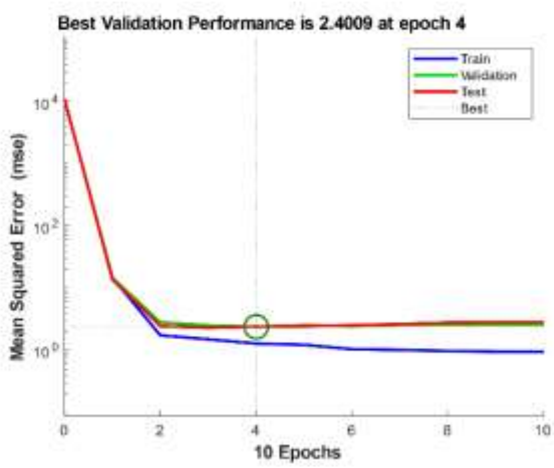
The data were obtained from two online tools provided by NASA, resulting in the ANN prediction where the days queried are set by thermal infrared radiation expressed in W/m^2

```
Algorithm 1 Data processing
Upload: nasa.dat and validation.dat
Divides nasa.dat data into training, validation and test sets
Defines the architecture of the ANN
Train the RNA
Validates the ANN
Calculates error and performance
Perform thermal infrared radiation prediction.
Select random data with validation data
Graph the prediction and the selected data
```

Table 1 Pseudocode used
Source: Own Elaboration

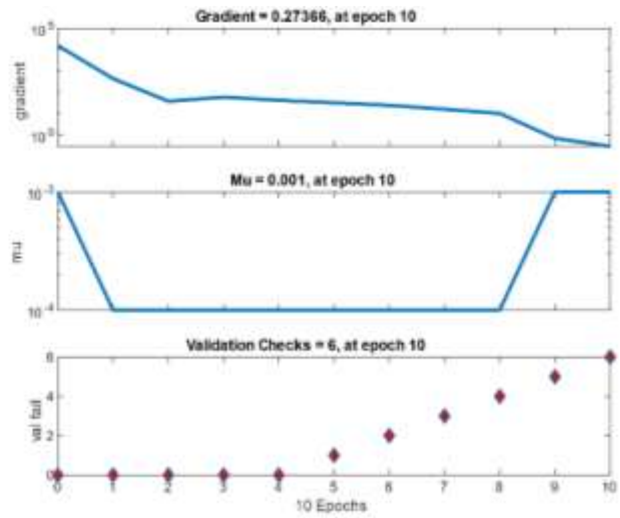
```
Algorithm 2 Data processing
Upload:  Gg.dat
Assigns emissions to individual variables
Determines molar masses of gases in g/mol
Defines the volume of the atmosphere in m^3
Calculates concentrations in ppm of CO2, CH4 y N2O
Sets atmospheric parameters
Assign greenhouse gas concentrations
Defines absorption coefficients of the gases in m^2/kg
Calculates atmospheric thermal infrared radiation
```

Table 2 Pseudocode used
Source: Own Elaboration



Graph 2 Evaluation and selection of the best ANN model
Source: Own Elaboration

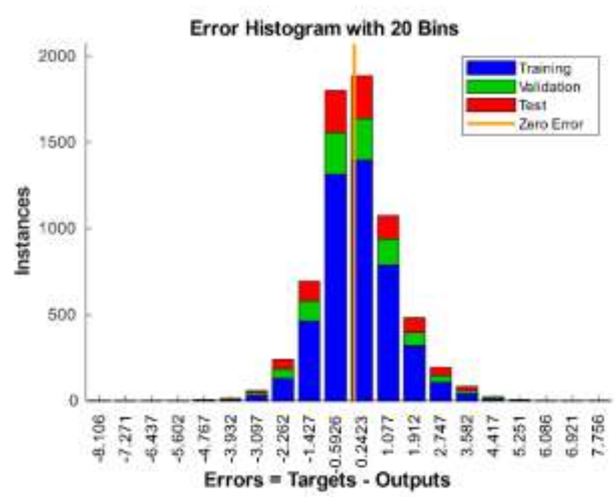
The mean square error is used to evaluate the accuracy of the ANN, it is the root mean square of the differences between the predicted values with the real values of the dataset. However, during the training of the network it was 2.4009 indicating that the model had its best performance after four training epochs.



Graph 3 Evaluation and selection of the best ANN model
Source: Own Elaboration

The gradient is the function that performs changes in weights and biases, in this situation it resulted in a value of 0.27366 during epoch 10. The parameter Mu controls the adjustments that exist within the training network. Mathematically speaking, it is multiplied by the gradient obtained from the backpropagation of the error determining the value of the adjustment of the weights. In this case, the learning rate has a value of 0.001 at epoch 10.

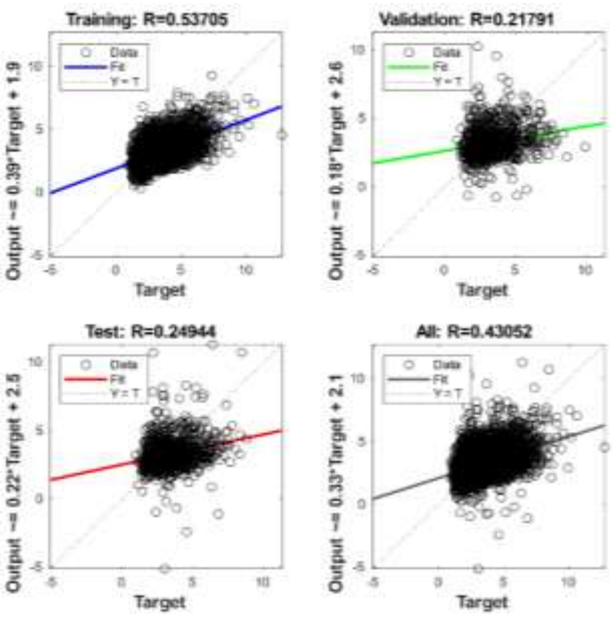
Validation checks are used to evaluate and compare the performance of the model, which in turn is closely related to other parameters such as precision, accuracy or mean square error. This check had 6 checks of which occurred at epoch 10. Also, one validation failure was found during training because it probably requires additional adjustments, modifying or augmenting the training data.



Graph 4 Distribution of errors
Source: Own Elaboration

The error histogram refers to the error distribution that exists in the network. For example, when training the ANN there is usually a set of data in training and test, therefore, test data can be used to make predictions, errors and actual values. In other words, errors can be the main difference between the actual and predicted output.

The graph shows 20 bins where the highest value of errors is in the range between -0.5926 and 1.077. Furthermore, it means comparing the actual values and the estimated values for a set of instances.



Graph 5 Training and evaluation of the neural network
Source: Own Elaboration

Training refers to adjusting the parameters of the ANN so that it can learn and make the appropriate prediction, using a set of inputs corresponding to targets known as expected output values. In particular, training was 0.53705, with an output of 0.39 and a test output of 1.9.

Validation is the evaluation of the performance of a data set that was separated that was not occupied during training and is used to verify what its performance might be on previously unseen data. The result of 0.21791 is the coefficient of determination, which ranges from -1 to 1. This means that the model has a weak positive correlation with the validation data.

The test indicates what the precision of the data is, of which gives a value of 0.24944 indicating that there is a slight positive correlation with an output of 0.22 representing the output of a given data set, while the target value of the validation checks is 2.5.

Finally, the last graph points to an average ANN across all the datasets mentioned above. Where the data was most concentrated was at point 5, which is the desired output.

7. Acknowledgements

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8. Conclusions

In conclusion, the application of artificial neural networks to atmospheric thermal infrared radiation makes it possible to model the relationship between this radiation and climate parameters. This process involved collecting accurate data on thermal infrared radiation and climatic variables such as temperature, humidity, atmospheric pressure, altitude and wind speed. They were also subjected to pre-processing including normalisation and splitting into different training, validation and test sets.

Subsequently, the feedback neural network was designed and trained with input layers for the weather variables, also hidden layers where it uses an activation function such as the ReLU function, and an output layer for thermal infrared radiation. The training of the network was performed using the training dataset by adjusting the hyperparameters where good performance was obtained in the validation set.

Finally, the performance of the network was evaluated on the test set to analyse whether it performed well in predicting thermal infrared radiation. It can then be concluded that it was successful in relating weather variables and radiation.

In summary, the application of artificial neural networks provides a useful tool to study, understand and predict atmospheric thermal infrared radiation, which can have applications in different areas such as meteorology, climatology and renewable energy.

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Processing and recognition of EMG signals through CNN networks for the control of electric vehicles

Procesamiento y reconocimientos de señales EMG mediante redes CNN para el control de vehículos eléctricos

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Abstract

The increase in autonomous driving technologies, as well as biometrics using biosignals from vehicle drivers, provide information that can be used for the development of personalized biosecurity and driving systems for each user. Currently, studies are being carried out on the extraction and classification of driver characteristics with great precision, to generate intelligent systems that are auxiliary and that help to safeguard the integrity of people while driving vehicles. This work presents the recognition of 5 hand gestures to control the driving actions of an electric vehicle using the EMG signals from the MYO™ bracelet, these signals have also been used to detect users and thus allow the use only of the people registered in the application. To perform gesture recognition, a convolutional neural network was trained and implemented for the classification of actions. Finally, a cross-validation was carried out to validate the reliability of the proposed system, obtaining 99.2% accuracy during the classification.

Convolutional Neural Networks, Biosecurity, Autonomous

Resumen

El incremento de las tecnologías de conducción autónoma, así como las biométricas mediante el uso de bioseñales provenientes de los conductores de vehículos, proporcionan información que puede ser utilizada para el desarrollo de sistemas de bioseguridad y de conducción personalizado para cada usuario. Actualmente se realizan estudios sobre la extracción y clasificación de características de conductores con gran precisión, con la finalidad de generar sistemas inteligentes que sean auxiliares y que ayuden a salvaguardar la integridad de las personas durante la conducción de vehículos. Este trabajo presenta el reconocimiento de 5 gestos realizados con la mano para el control de las acciones de conducción de un vehículo eléctrico utilizando las señales EMG procedentes del brazalete MYO™, estas señales también han sido utilizadas para detectar a los usuarios y así permitir el uso únicamente de las personas registradas en la aplicación. Para realizar el reconocimiento de los gestos, se entrenó e implemento una red neuronal convolucional para la clasificación de las acciones. Finalmente, se realizó una validación cruzada para validar la confiabilidad del sistema propuesto obteniendo un 99.2% de exactitud durante la clasificación.

Red Neuronal Convolucional, Bioseguridad, Autónomos

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1. Introduction

Gesture recognition refers to the process of interpreting and classifying the meaningful movements of a person's limbs, hands, face and head. Gesture recognition is of great importance in the field of research and technological development for the development of human-machine interfaces.

With the technological development that has taken place in recent years and the great progress in the field of artificial intelligence, there is now a wide variety of smart devices (tablets, mobile phones, bracelets, watches, gadgets, etc.) which are equipped with a large number of sensors (accelerometer, gyroscope, GPS, heart rate sensor, bioimpedance sensor, EMG sensors, etc.) thus allowing the development of human-machine interfaces [1, 2, 3, 4, 34]. The use of sensor data from these types of devices has been of great interest to researchers and developers of intelligent applications (Apps) for making inferences in different aspects of life [5]. Previously, application development had been for health monitoring, fitness tracking and security [6, 7, 8].

To perform the task of human activity recognition through the use of sensors, two main actions have to be taken into account. The first action to be taken into account is to perform the segmentation of the signal containing the activity (or gesture) to be recognised during monitoring. In the case of electrical signals as it is for our case study of the present work, is to perform a segmentation in time steps of the signal, this action can be carried out by means of a sliding window of fixed length, dividing the signal into equal segments. However, when performing a segmentation by sliding window, there is a question about the size of the window to be used and to have as a consequence a good accuracy in the task of classification or recognition of the signal in question.

The solution to this task has been proposed and carried out in different ways [9, 10, 11]. The second action that has to be performed is an extraction of the features of the segmented signal in order to perform a good signal classification or recognition task.

Carrying out the task of extracting signal features can be done by using classical techniques such as the wavelet transform [12], fast Fourier transform (FFT) [12], common spatial pattern (CSP) [13], autoregressive models [14], etc. However, the accelerated progress in the development of artificial intelligence (AI) algorithms has generated a new approach in the extraction of features from a signal based on deep learning, whose main idea focuses on the automatic learning of the features extracted from the raw data coming directly from the sensors without having performed a preprocessing to the signals [9, 15]. However, sometimes some filtering technique can be used for signal smoothing, in order to obtain the cleanest possible signal for an AI or Machine Learning system [16].

For this work, a convolutional neural network (CNN) architecture was implemented for hand gesture recognition using the MYOTM bracelet as the EMG signal acquisition system. The reason for using CNN networks is because these types of architectures perform excellent feature extraction from the data, which makes it unnecessary to perform signal pre-processing or feature extraction from the signals.

2. State of the art

Previously it has been mentioned that there are already previous works on gesture recognition through EMG signal processing using devices such as the MYO, or by means of sensors placed directly in the area where the signal is required to perform a specific task [4]. In order to perform the recognition of movements, the first step is to perform the segmentation (beginning and end) of each gesture or stroke properly, this action can be performed automatically as in [20] or by visual inspection of the signal and perform it manually [21].

EMG signals have been used for the development of vehicles for disabled people, where some series of adaptations have to be made to be operated by hands. Carrying out this task is not easy, because the person has to control all the functionalities of the vehicle with the same limb. This can increase the risk of a car accident [17].

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Driving a car provides significant forms of independence, especially for people with disabilities. Since driving can provide an easy and comfortable form of mobility, it can help prevent social isolation, making activities such as participation in work and social interactions easier [18].

There are several types of injuries, which lead to many disabilities related to disabled drivers, so there must be the generation and development of new devices that contribute to the adaptability or inclusion of people in working life, as well as to lead as independent a life as possible [19].

3. Convolutional Neural Networks

Convolutional Neural Networks (CNNs) are hierarchical architectures whose structure and development are inspired by the biological visual system [22]. The difference between a classical or standard neural network architecture (ANN) and CNNs is that in addition to using fully connected layers, they perform a series of convolution operations, where learning filters are used to slide along the input data. In general terms, a CNN architecture can be described as follows:

Convolutional Layer

For a one-dimensional system, the convolution between two vectors $x \epsilon \mathbb{R}^n$ and $f \epsilon \mathbb{R}^m$is a vector $c \epsilon \mathbb{R}^{n-m+1}$, where the vector f also known as the convolution filter, which slides along the vector *x*, obtaining the scalar product at each step and whose obtained values form the output of the convolutional layer. Such that $c_i = f^T x_{i:i+m-1}$, where each element of c is calculated as the scalar product between the vector *f* and a sub-segment of *x*.

Non-linearity

To learn the non-linearity of systems, the convolutional layer is usually accompanied by a non-linear activation function applied pointwise to the output. Three activation functions are commonly used: sigmoidal, hyperbolic tangent and ReLU (Rectified Linear Unit).

Pooling layer

This layer commonly follows a convolutional layer, whose objective is to reduce the dimension of the representation obtained after convolution. There are two ways to perform this task, to obtain a maximum or an average of small rectangular blocks of the data.

Fully connected layer

After performing the process in the convolutional layers, it is necessary that the output of these layers is converted into a vector which will be used in the classification. In order for a CNN architecture to learn non-linear dependencies, one or more fully connected layers can be used to perform the classification.

Soft-Max layer

Finally, the output obtained in the last layer is passed through a Soft-Max layer that obtains the probability estimation of the classes. In general, these are the layers present in a CNN architecture, which are coupled to form a CNN network, which can be trained as a whole.

3.1 Implemented Architecture.

For the present work, the CNN architecture shown in Figure 1 has been proposed, where it can be seen that the signals come from the Myo™ bracelet, which has an Inertial Measurement Unit (IMU) equipped with an accelerometer, a gyroscope, a magnetometer and sensors for EMG signals. Once the signals are captured, they are sent to the convolutional neural network for further processing and classification. The architecture of the CNN proposed in Figure 1 is described as follows.

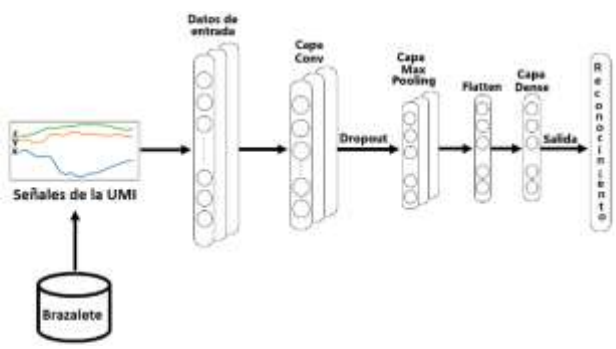

Figure 1 Proposed Convolutional Neural Network (CNN) architecture

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The architecture shown in Figure 1 consists of a convolutional layer with 16 convolutional filters of size 1×8 using a ReLU activation function for feature extraction. After the convolutional layer a *dropout* with a rate of 0.9 has been used to avoid over-learning. Finally, a fully connected layer (Dense) with *Soft-Max* activation function has been implemented to perform the classification into 12 classes. This architecture was trained for 50 epochs using the Adam optimiser and a *batch size* of 36 and a learning rate of 10^{-5}.

The architecture presented in this paper was implemented based on the works [10, 23, 24], however, the final architecture is different from the aforementioned works. The selection of the number of layers, the activation function, dropout rate, pooling type, etc., as well as other hyper-parameters were based on the studies [25, 26, 27, 35]. However, the final design of the architecture was basically obtained empirically, i.e. by trial and error until the CNN network design that obtained the best results was found.

4. Experimentation and Results

In order to test the performance of the system proposed in this work, a database large enough to have data in the training phase and in the test phase was generated. The data acquisition was performed using a commercial interface called MYO™, a portable device developed by Thalmatic Labs Inc., which is a bracelet made of an expandable material that allows it to stretch and contract, thus allowing it to adapt to the physiognomy of each user's arm. This armband is equipped with an Inertial Measurement Unit (IMU) and 8 sensors for measuring electromyogram (EMG) signals.

The IMU of the Myo™ bracelet consists of an accelerometer, a gyroscope and a magnetometer, all delivering three-dimensional signals. This device can be connected to a device (computer, tablet, mobile phone, etc.) and the sampling rate for each IMU sensor is 50Hz and 200Hz for the EMG sensors. This bracelet has been used in several research works [28, 29, 30] obtaining good results, which is why we chose to use the Myo™.

Figure 2 Gestures to recognise with the CNN network

In this work, the recognition of 5 gestures $(t_1 - t_5)$, which are shown in figure 2, was carried out to control the forward, backward, left turn, right turn and stop functions. For the experimental analysis of the signals, it is common to carry out a preprocessing of these, which allows the extraction of properties and characteristics of a group of data. Some of the most common ways is to work in frequency space, since in this way the frequency response of a system can be found, although it is also possible to work in time space [31]. Another technique widely used in the task of signal preprocessing is the filtering of these in order to obtain the characteristic frequencies of the signals [32], another common technique in signal preprocessing is to obtain the mean square error [33], the fast Fourier transform, among others.

Thanks to advances in the field of Artificial Intelligence, the signal preprocessing stage can be omitted for some systems, because Artificial Intelligence algorithms can take the raw data or without preprocessing to extract features that can help the system during the training and testing phase. For the present work we took the data delivered by the bracelet and sent it directly to a CNN architecture described above. The database is built by 50 samples for each class (gesture), however, an analysis has been performed by taking different numbers of samples to test the proposed CNN architecture and thus observe how susceptible the proposed neural network is to the number of samples.

To analyse the performance of the proposed architecture, we chose to use k-fold cross-validation, which is a widely used statistical technique to evaluate the performance of classification algorithms. To perform the cross-validation (CV), the entire data must be divided into k groups of the same size. Once the database is divided, k-1 groups are used for training the system and the remaining group is used for testing. This process is done k times using a different test group for each iteration, generating in each iteration a $Error_n$ whose average is used as the final estimate.

$$estimadoer\ VC = \frac{1}{K}\sum_{n=1}^{k}(Err_n) \qquad (1)$$

To perform the estimation in this work, a value of *k*=10 was used, which means that, from the database, 90% of the samples were taken for training and the remaining 10% for testing. This value of *k* is the most recommended since larger values may cause the variance of the estimation to increase. Plot 1 shows the averaged ROC curve for all classes. The area under the curve (AUC) is 1.0. So it can be said that the classifier (CNN) is able to separate the classes perfectly. To perform the estimation in this work, a value of *k*=10 was used, which means that, from the database, 90% of the samples were taken for training and the remaining 10% for testing.

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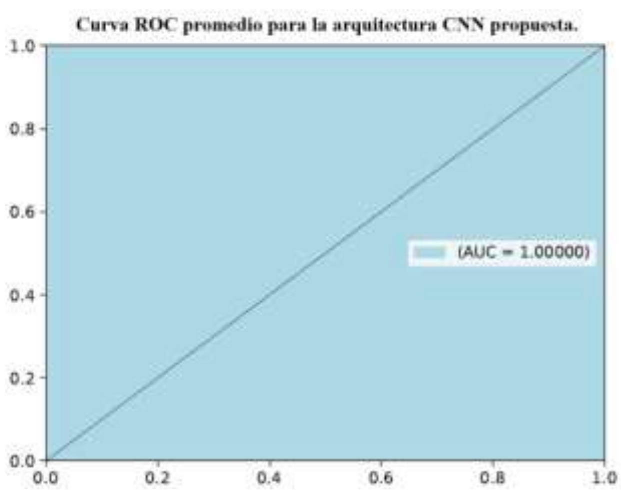
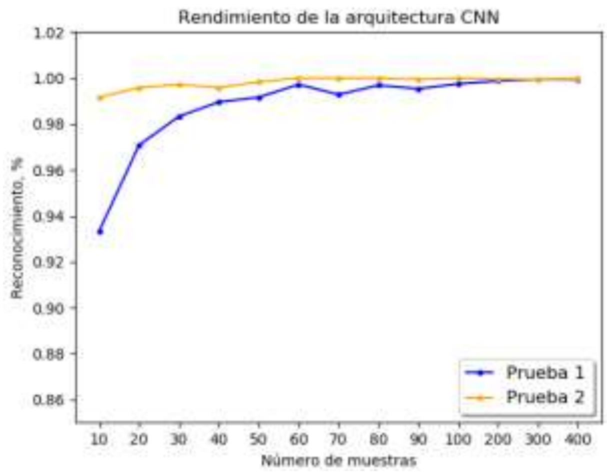


Graph 1 Average ROC curve



Graph 2 Recognition results obtained for different numbers of samples in different tests

The results obtained from the recognition analysis are presented in graph 2, where the performance of the CNN architecture proposed for the classification of the 5 gestures from EMG signals can be observed. From this analysis it can be seen that a good classification of the classes with few samples is achieved by using Convolutional Neural Networks. The results shown refer to the average of the cross-validation for the different numbers of samples used in each test.

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6. Funding

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7. Conclusions

This work has proposed a method for performing gesture recognition for the control of actions during the driving of a vehicle based on electromyography (EMG) signals. The results obtained have shown that with the use of artificial intelligence algorithms it is possible to obtain highly accurate gesture recognition. The proposed CNN architecture proved to have sufficient capacity to recognise without problems the 5 gestures of the EMG signals captured from the 8 sensors placed on a person's arm.

Another observation to be taken into account is that it is not necessary to use many samples per class to obtain a good classification rate.

At the moment, the study shows promising results for the recognition of gestures capable of controlling some actions during the driving of electric vehicles, however, there is uncertainty as to whether it is possible to implement more control actions for electric vehicles that show similar results, so research on this topic will continue as future work, as well as the implementation and design of vehicles controlled by EMG signals for people with motor disabilities and for biosafety systems.

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Unsupervised learning model to determine a classification based on the cost-benefit ratio of school notebooks in Mexico

Modelo de aprendizaje no supervisado para determinar una clasificación basada en la relación costo-beneficio de los cuadernos escolares de México

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Abstract

One of the most demanded items at the beginning of each school year is the notebook besides, there are different ways of classifying them, the result is usually biased towards their characteristics, not their cost-benefit ratio. Taking studies carried out by PROFECO on the most purchased notebooks in Mexico as a source of reference and comparison, this paper shows as well as compares the results of a proposed unsupervised learning model to classify school notebooks in a cost-benefit ratio.

Comparison, Classification, Notebooks, Unsupervised learning

Resumen

Uno de los artículos más demandados al inicio de cada ciclo escolar es el cuaderno y aunque existen diferentes formas de clasificarlos, el resultado suele estar sesgado a sus características y no a su relación costo-calidad. Tomando como fuente de referencia y comparación estudios realizados por la PROFECO de los cuadernos más comprados en México, en este trabajo se muestran y comparan los resultados de un modelo propuesto de aprendizaje no supervisado para clasificar los cuadernos basándose en una relación costo-beneficio.

Comparación, clasificación, Cuadernos, aprendizaje no supervisado

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Introduction

Every school year, Mexican parents must spend an approximate amount of 53% of their monthly income (WorldRemit, 2022); according to studies, the most demanded item is the notebook; however, their average prices have increased by 123% compared to the previous year (Valladolid, 2023). Therefore, it is necessary to have tools that allow the best possible decision to be made with an increasingly tight budget.

One of these tools is the analysis developed by the Federal Consumer Attorney's Office (PROFECO, 2023), which is in charge of make quality studies about multiple products along with brands available in Mexican market in addition to report them publicly; nonetheless, it issues recommendations so that consumers can establish comparisons as well as make the best purchase decisions. Nonetheless, frequently these studies, as well as all those carried out by PROFECO, are based only on a descriptive classification more than on a formal statistical analysis to determine the best products considering the cost-benefit ratio.

This paper describes the results of a set of techniques based on unsupervised learning to classify school notebooks in Mexico according to their cost-benefit ratio in addition to taking into account the studies carried out by PROFECO.

Objectives

General

– Determining through artificial intelligence techniques the best school notebooks using their cost-benefit ratio.

Specifics

– Complementing the studies carried out by PROFECO.

– Helping the consumer to take better decisions when they have a tight budget.

State of art

Unsupervised learning

Within artificial intelligence, there are algorithms which do not need to be trained in order to classify a dataset; conversely, their classification is done through the inherent characteristics of each element, this type of technique is called unsupervised learning classification or clustering.

The techniques used are particularly useful when there is no prior labeling, that is, when it is unknown how a dataset can be organized, notwithstanding, it is necessary classifying it. Furthermore, these techniques are often used for comparison purposes as well as to get feedback between the results (classification) produced by a model against those determined by a specialist (Urueta *et al.*, 2021).

K-means

Perhaps, this is the best-known clustering technique, its operation consists of splitting the data into a number *k* of groups. Each data, also called observation, is assigned to one group or another depending on how close the observation is to the average value of each group.

Elbow method

A problem with the *k*-means method is that it is necessary to specify the number *k* of groups into which the database will be separated beforehand; to accomplish this task, the elbow method was used.

The elbow method is a measure to calculate the sum of squared error (SSE) between the mean distance and all other data points in the same group. It can formally be defined as:

$$SSE = \sum_{i=1}^{n} (x_i - \bar{x})^2 \quad (1)$$

It is needed to calculate the SSE values and then plotted them from 2 to *n*; thus, if we show the graphic, the point where the SSE or inertia values start decreasing in a linear manner will be the recommended *k* value to classify the database.

Principal Component Analysis: PCA

This technique allows to reduce the dimensions of a dataset, trying to preserve the greatest variation. It works by searching for possible correlations by means of lines, planes, and hyperplanes in the original space.

Pearson correlation coefficient

It is a measure which determines how two variables are linearly related. This coefficient is represented by the letter *r*. The result will be from -1 to +1. It can be interpreted as in Figure 1.

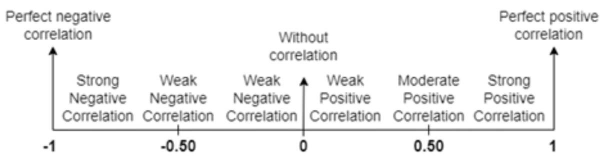

Figure 1 Interpreting a correlation analysis

PROFECO

The Federal Consumer Attorney's Office, abbreviated as PROFECO in Spanish, seeks to empower the consumer through the effective protection of the exercise of their rights and citizen trust, promoting a reasoned, informed, sustainable, safe as well as healthy consumption, in order to correct market injustices, strengthen the internal market along with the well-being of the population (e.Economía, 2022). In this sense, PROFECO has the National Consumer Protection Laboratory (LNPC, by its acronym in Spanish), dedicated to preparing as well as publishing quality studies of widespread consumption products on their impact on nutrition, safety along with economy (AMEXCID, 2018).

Materials and methods

Materials

- For this study, the PROFECO databases were used, this can be consulted from (PROFECO, 2022).

- Python programming language for database analysis.

Methods

- Normalize the database

- Apply artificial intelligence techniques, such as: PCA in addition to unsupervised classification methods to the normalized database.

- Compare the results obtained by the model with those reported by PROFECO.

- Report the results in a clear way.

Results

Pearson correlation analysis applied on the original database (see Figure 2) demonstrates the following:

- There is a moderate positive correlation between the cost with the grams of sheets indicated and the real one.

- There is a moderate positive correlation between the classification proposed by PROFECO and the resistance of the sheets and cover.

- There is no correlation between the cost and the classification proposed by PROFECO.

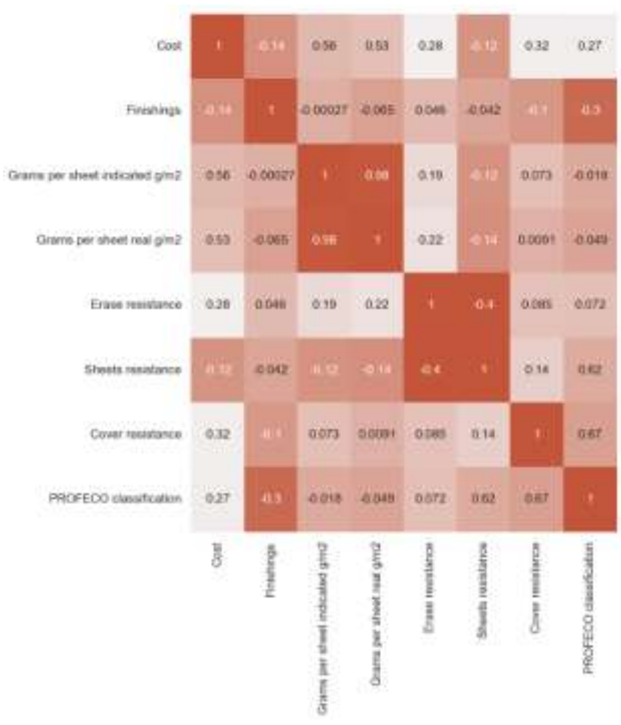

Figure 2 Correlation analysis with original classification

Subsequently, the elbow method was applied on the database to determine the number of classes recommended to classify the dataset.

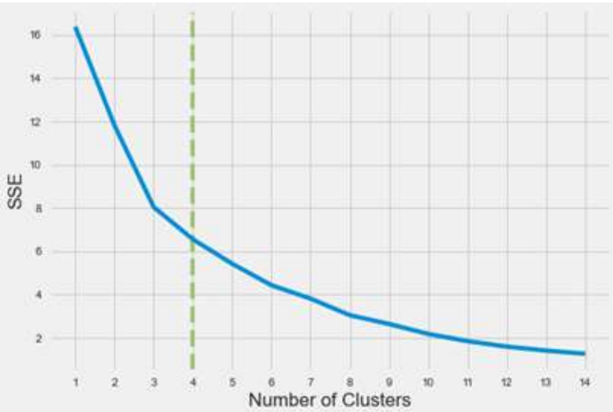

Figure 3 Results of the elbow method

Once the number of clusters was determined (see Figure 3), the database was classified using *k*-means with a value *k* = 4. The classification obtained was added to the database, afterward a correlation analysis was made again. The results of this analysis are presented in Figure 4.

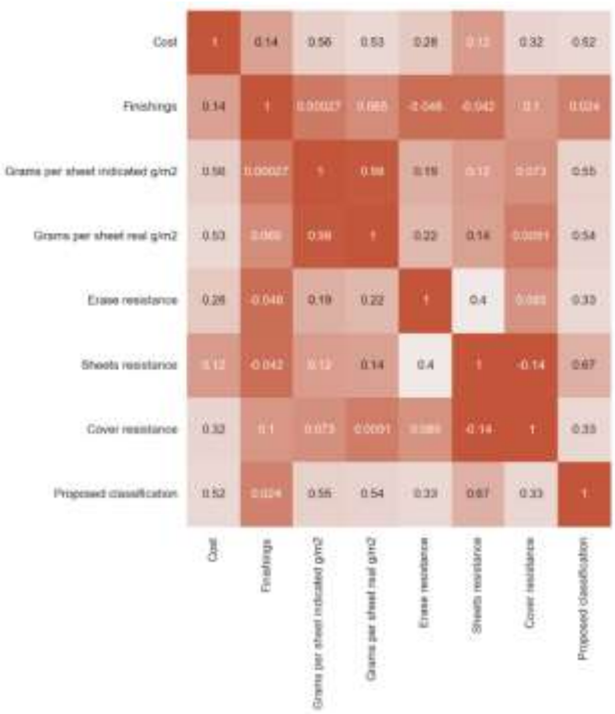

Figure 4 Correlation analysis with the proposed model classification

From the above results, the following can be inferred:

- There is a moderate positive correlation between the classification generated and the cost.
- There is a moderate positive correlation between the classification generated and the grams of indicated sheets.
- There is a moderate positive correlation between the classification generated and the real grams of sheets.
- There is a moderate positive correlation between the classification generated and the resistance of the sheets.

As a result, Table 1 shows a comparison between the qualification assigned by PROFECO against the carried out by the proposed model which considers the cost-benefit ratio.

Model	Qualification Assigned by PROFECO	Classification of the Proposed Model
Scribe 7510	Very good	Excellent
Estrella Único	Very good	Excellent
Manufacturas 8-A	Very good	Excellent
Estrella/ Star Kid	Good	Excellent
Sazz	Sufficient	Sufficient
U-Pak	Sufficient	Sufficient
Norma Cosido	Excellent	Excellent
Estrella Cosido	Excellent	Excellent
Office Max Espiral	Very good	Excellent
Scribe Excellence	Very good	Good
Scribe In Black	Very good	Very good
Manufacturas 8-A	Very good	Very good
First Class 5038	Very good	Very good
First Class 5040	Very good	Very good
First Class 4517	Very good	Very good
Norma Jean Book	Very good	Very good
Scribe Clasico Cosido	Very good	Excellent
Scribe Kids Cosido	Very good	Excellent
First Class 4507	Good	Very good
Estrella Drive Linea A	Good	Good
Scribe In Colors 1070	Good	Very good
First Class Cuaderno Cosido 9408	Good	Sufficient
First Class Profesional 5039	Good	Sufficient
Scribe Poly Cover 2050	Good	Very good
Norma	Good	Sufficient
Estrella 0520	Good	Sufficient
First Class Cosido Profesional 9214	Good	Sufficient
Norma Click Urbana	Good	Sufficient
U-Pak 1157525405	Good	Sufficient
Norma Kiut	Good	Sufficient
Norma Girly Notes	Sufficient	Sufficient
Norma Uno	Sufficient	Sufficient
Nine To Five	Sufficient	Sufficient

Table 1 Comparisons between the PROFECO classification against the proposed model results

Finally, for a better visualization of the classified notebooks, a scatterplot was made reducing the dimensions of the database to 3 by means of PCA. In this scatterplot, the points with the same color mean that they belong to the same class (see Figure 5).

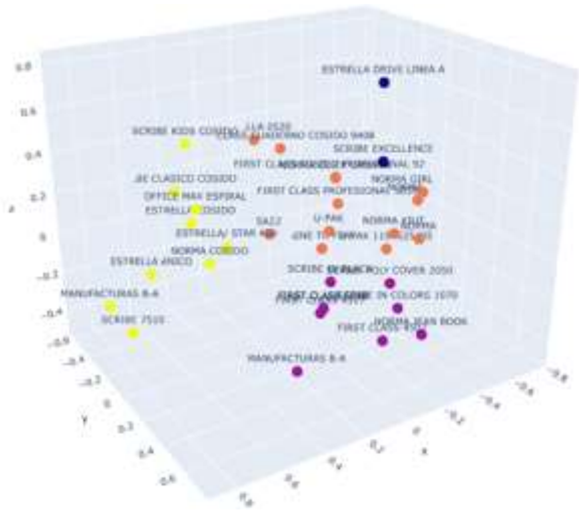

Figure 5 Scatterplot generated with PCA

Acknowledgment

To PROFECO for its studies published about school notebooks in Mexico.

Conclusions

The aim of this paper was to propose an unsupervised learning model classifying notebooks in a cost-benefit ratio, based on the studies accomplished by PROFECO on the most purchased notebooks in Mexico.

The proposed model considers both the cost and the characteristics of the notebooks, such as the number of sheets, the quality of the paper, the type of binding, and the design of the cover. The classification performed by PROFECO, on the other hand, focuses more on the resistance of the sheets and covers, which may not reflect the actual needs or preferences of the consumers.

One of the challenges that we faced was to obtain reliable and updated data on the prices along with features of the notebooks in the Mexican market. We used web scraping techniques to collect data from online sources, nevertheless we acknowledge that this may not capture the full range of notebooks available or their actual prices in different regions. Future work could involve conducting surveys or interviews for consumers together with sellers to obtain more accurate and comprehensive data.

This paper provides a novel and useful tool for consumers to establish comparisons and, consequently, buy notebooks that offer the best value for their money.

It also offers insights for sellers to improve their marketing strategies and product quality based on the cost-benefit analysis. Moreover, it contributes to the field of unsupervised learning by applying a clustering algorithm to a real-world problem that has not been explored before. We hope that this paper will inspire further research as well as innovation in this area.

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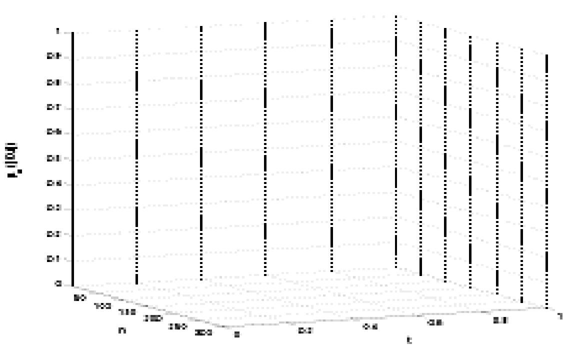

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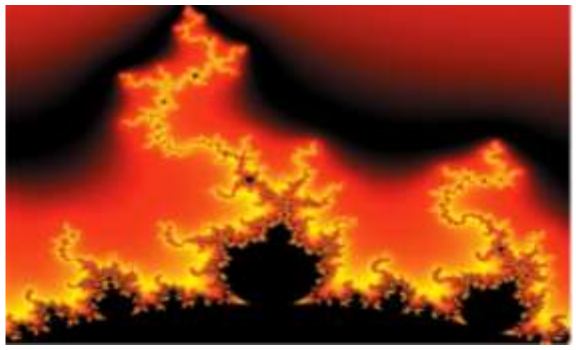

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