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Journal of Technological Operations

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Presentation of the content

In the first article we present, *Design of a simulator for the energy evaluation of cold rooms* by VALLE-HERNANDEZ, Julio, DE SANTIAGO-HERRERA, Maria Guadalupe, MANZANO-MUÑOZ Meily Yoselin and ROMÁN-AGUILAR, Raúl, with adscription in the Universidad Autónoma del Estado de Hidalgo, in the next article we present, *Temperature control based on Fuzzy Logic using Maximum Center Method* by CASTAÑEDA-DELGADO, Jaime, ESQUIVEL-SALAS, Abraham, SALAS-GUZMÁN, Manuel Ignacio and MOTA-GARCIA, Juana, with adscription in the Instituto Tecnológico Superior Zacatecas Norte, in the next article we present, *Data acquisition module for the operation of the Neural Network for crop rotation and soil analysis in a Greenhouse* by RAFAEL-PÉREZ, Eva, MORALES-HERNÁNDEZ, Maricela, NAVARRETE-INFANTE, Nestor Manuel and RIOS-MALDONADO, Vicenta, with adscription in the Instituto Tecnológico de Oaxaca, in the next article we present, *Structural analysis, simulation and validation as a strategy for product design* by OJEDA-ESCOTO, Pedro Agustín, with adscription in the Universidad Tecnológica de Aguascalientes.

Content

Article **Journal of Technological Operations**
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Design of a simulator for the energy evaluation of cold rooms

Diseño de un simulador para la evaluación energética de cámaras frigoríficas

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Abstract

This paper presents the design of a simulator to evaluate the performance of cold rooms, which allows to determine the feasibility of its implementation. The design is based on the selection of construction materials and the dimensions of the cold rooms, to later determine the thermal loads that allow estimating the heat to be removed from the product. From the thermal loads, the modeling of the thermodynamic cycle, simple steam compression cycle, is obtained the work of the compressor and the coefficient of performance of the system are obtained. The evaluation of the performance of the simulator was carried out for climatic conditions of the municipality of Apan Hidalgo, where the storage of poultry meat in a range of 0°C to 4°C was considered. The proposed cold room can store a maximum capacity of 500 birds. As a result, the simulator obtains the thermal loads associated with the cooling process, the behavior of the cooling cycle, the heat removed by the system, the work of the compressor, the number of cycles per day, the behavior of the temperature of the product inside the cold rooms and the energy consumed by the system.

Cold room, Poultry conservation, Energy consumption

Resumen

En este trabajo se presenta el diseño de un simulador para evaluar el desempeño de cámaras frigoríficas, lo que permite determinar la viabilidad de su implementación. El diseño parte de la selección de materiales de construcción y las dimensiones de la cámara, para posteriormente determinar las cargas térmicas que permitan estimar el calor a retirar del producto. A partir de las cargas térmicas se obtiene el modelado del ciclo termodinámico, ciclo simple de compresión a vapor, y se obtiene el trabajo del compresor y el coeficiente de desempeño del sistema. La evaluación del desempeño del simulador se realizó para condiciones climáticas del municipio de Apan Hidalgo, en donde se consideró el almacenamiento de carne avícola en un rango de 0°C a 4°C. La cámara frigorífica propuesta alcanza a almacenar una capacidad máxima de 500 carcasas. Como resultados el simulador obtiene las cargas térmicas asociadas al proceso de refrigeración, el comportamiento del ciclo de refrigeración, el calor retirado por el sistema, el trabajo del compresor, el número de ciclados al día, el comportamiento de la temperatura del producto dentro de la cámara y la energía consumida por el sistema.

Cámara frigorífica, Conservación avícola, Consumo energético

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1. Introduction

Simulation is developing more and more in different fields of study due to technological advances in software and hardware. The uses of simulation are given in different areas, in design and operation of systems, application in industrial projects, in economic systems, in health services, among others.

This work presents the design of a simulator that allows evaluating the operating conditions of a cold room, the simulator is intended to be a tool to determine the feasibility of using a certain cold room depending on the product to be stored and the geographical region where it will be installed.

The design of the cold room, which will be simulated to determine its behavior, will depend both on the variable operating conditions and the climatic characteristics of the region where it will be installed, seeking to keep the refrigerated product in the temperature range that allows its optimum preservation.

The modeled refrigeration system uses a simple compression cycle. Propane (R-290) is selected as the refrigerant fluid, as it is a natural refrigerant with good energy efficiency (Gas Servei. n.d.). At present, hydrocarbons such as propane are replacing commonly used refrigerants that damage the ozone layer or contribute to global warming.

The design of the simulator consists of the mathematical modeling of the state variables, the thermodynamic analysis of the cycle and the calculation of thermal loads. For this design it is necessary to know the characteristics of the product, the climatic conditions of the site, the properties of the construction materials of the chamber and the number of individuals that will enter the enclosure.

The simulator solves the differential equations corresponding to the mathematical model and delivers as results: the heat discarded by the condenser, the work done by the compressor, the number of cycles, the coefficient of performance (COP), the product temperature and the amount of energy consumed throughout the day.

2. Methodology

The methodology to be developed in this work is based on the following points:

- Design of the cold room.
- Mathematical modeling of the thermal loads.
- Modeling of the cold room
- Modeling of the refrigeration cycle
- Modeling of the cold room with refrigeration cycle
- Simulator integration
- Simulator evaluation

3. Development

3.1 Design of the cold chamber

An important part of the cold room design is to know the characteristics of the materials to be used in order to obtain the required insulation.

The proposed sizing for the cold room is shown in Table 1, having a heat transfer area of 40.9 m^2 and a volume of 23.6 m^3.

Cold storage	
Height (m)	3.50
Length (m)	2.70
Width(m)	2.50
Aisle width (m)	0.90
Storage area width (m)	0.90
Door	
Height (m)	2.50
Length (m)	0.90

Table 1 Refrigerator dimensions
Source: Own Elaboration

Polyurethane as an insulating material is considered the optimum material for the design of the enclosure due to its low thermal conductivity, since it allows less heat to pass into the interior of the cold room. Table 2 shows the materials of construction for cold rooms.

Wall material	Thermal conductivity ($\frac{W}{m°K}$)	Thickness (m)
Polyurethane	0.028	0.075
Brick	0.87	0.16
Mortar	1.40	0.04
Door material		
Polyurethane	0.028	0.02
Aluminum	205	0.05

Table 2 Construction Materials
Source: Own Elaboration

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The refrigeration system uses a simple compression cycle, using a hydrocarbon (HC) as refrigerant. It is proposed to use propane R-290 as it is a natural refrigerant, and is currently being used for industrial refrigeration replacing the R-134a. Table 3 shows the physical properties and Table 4 the flammability properties of the refrigerant.

Refrigerant R-290 (Propane)		
Lower flammability limit		Auto-ignition temperature (°C)
In volume (%)	In weight ($\frac{Kg}{m^3}$)	
2.10	0.038	460

Table 3 Physical properties
Source: (Gas Servei. n.d.).

Molecular weight	Boiling temperature (°C)	Critical temperature (°C)	Critical pressure (bar)	Calor latente ($\frac{KJ}{Kg}$)
44.1	-42	96.7	42.48	342

Table 4 Flammability Properties
Source: (Gas Servei. n.d.).

3.2 Calculation of thermal loads.

The thermal load is the amount of heat that must be removed from the site to be cooled, to reach the desired temperature, in the design of the simulator the following thermal loads are considered (Sanchez. M. & Pineda. I. 2001):

– Thermal load due to product cooling, is obtained by the following equation:

$$Q_P = \frac{m_p * Cp_p * \Delta T}{t} \quad (1)$$

Where:
m_p the mass of the product.
Cp_p is the specific heat of the product.
ΔT is the temperature difference, initial temperature minus the final temperature of the product.

– Thermal load due to transmission losses in walls, which is obtained from the following equation:

$$Q_{T1} = U_1 * A_1 * \Delta T \quad (2)$$

Where:
U_1 is the overall heat transfer coefficient in the walls.
A_1 is the area of the enclosure
ΔT is the temperature difference, outside air temperature minus inside air temperature.

The global coefficient in the walls, is obtained as:

$$U_1 = \frac{1}{\frac{1}{h_1}+\frac{e_1}{k_1}+\frac{e_2}{k_2}+\frac{e_3}{k_3}+\frac{1}{h_2}} \quad (3)$$

Where:
e_1 is the thickness of the insulation.
e_2 is the thickness of the brick.
e_3 is the thickness of the mortar.
h_1 is the convective coefficient inside the chamber.
h_2 is the convective coefficient on the outside of the cavity.
k_1 is the thermal conductivity of the insulation.
k_2 is the thermal conductivity of the brick.
k_3 is the thermal conductivity of the mortar

– Thermal load due to transmission losses at the door is obtained from the following equation:

$$Q_{T2} = U_2 * A_2 * \Delta T \quad (4)$$

Where:
U_2 is the overall heat transfer coefficient at the door.
A_1 is the area of the door.

The overall coefficient at the door is obtained as:

$$U_1 = \frac{1}{\frac{1}{h_1}+\frac{e_1}{k_1}+\frac{e_4}{k_4}+\frac{1}{h_2}} \quad (5)$$

Where:
e_4 is the thickness of aluminum.
k_4 is the thermal conductivity of aluminum.

– Calculation of the sensitive load of people is obtained from the following equation:

$$Q_e = N_e * Qs_e \quad (6)$$

Where:
N_e is the number of people entering the enclosure.
Qs_P is the sensible heat per person.

– The thermal load produced by lamps is obtained from the following equation:

$$Q_l = N_l * P \quad (7)$$

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Where:
N_l is the total number of lamps
P is the lamp wattage

– Thermal load by infiltration of outside air is obtained from the following equation:

$$Q_I = Q_1 + Q_2 \quad (8)$$

Where:
Q_1 is the infiltrated heat due to technical air renewals.
Q_2 is the infiltrated heat due to equivalent air renewals

– The infiltrated heat due to technical air renewals is obtained from the following equations:

$$Q_1 = m * \Delta h \quad (9)$$

$$m = V * \rho * n \quad (10)$$

Where:
m is the mass of the air
Δh is the enthalpy difference of the air, inside and outside the enclosure
V is the volume of the enclosure
ρ is the air density
n is the number of technical air renewals

The infiltrated heat due to the equivalent air renewals is obtained by the following equations:

$$Q_2 = m * \Delta h$$
$$m = V * \rho * \theta \quad (11)$$
$$V = \frac{a*H}{4}\sqrt{0.072} * H * \Delta T \quad (12)$$

Where:
V is the air volume
θ is the door squeeze time
a is the width of the door
H is the height of the door
ΔT is the difference in outside air temperaturas

– Total thermal load.

In an area to be conditioned, the total thermal load results from the sum of the thermal loads involved in the cooling process.

$$Q_L = Q_e + Q_l + Q_p + Q_{T,1} + Q_{T,2} + Q_{\mathrm{I}} \quad (13)$$

3.3 Camera modeling

The modeling of the chamber allows predicting the behavior of the air temperature inside the enclosure without considering the cooling system. The change in the chamber temperature depends mainly on the climatic conditions of the site, from the thermal loads due to infiltration, and is obtained by the following equation:

$$\frac{dT}{dt} = \frac{U_1*A_1+U_2*A_2}{m_a*Cp_a}(T_e - T_i) \quad (14)$$

Where:
m_a is the mass of air
Cp_a is the specific heat of air.

Other important considerations for determining the temperature inside the chamber are the heat generated by the people entering the chamber and the lamps inside, which are determined with equations (6) and (7). In addition to these loads, the heat of the product must be considered, which can be estimated from equation:

$$Q_P = h * A * \Delta T \quad (15)$$

Where:
h is the convective coefficient of the product.
A is the average total area of the product.
ΔT is the difference in product temperatures, air temperature inside the chamber minus average product temperature.

The change in temperature of the product entering the chamber is obtained as:

$$\frac{dT_P}{dt} = \frac{Q_P}{m_P*Cp_P} \quad (16)$$

Where:
Q_P is the heat of the product.

The temperature of all the product inside the chamber, incoming product plus stored product, is obtained from the following equation:

$$T = \left(\frac{P_t-P_e}{P_t} * T_c\right) + \left(\frac{P_e}{P_t} * T_P\right) \quad (17)$$

Where:
P_t is the total product quantity.
P_e is the amount of product entering.
T_c is the temperature of the air inside the chamber.

T_P is the temperature of the entering product.

3.4 Analysis of the refrigeration cycle

The analysis of the refrigeration cycle allows to know the behavior of the system, considering a vapor compression cycle using R-290 as refrigerant (Webbook. n.d.). The thermodynamic states of the refrigeration cycle are shown in Figure 1, which are (Cengel, & Boles, M. 2001):

a) State 1, saturated steam at the refrigeration temperature.
b) b) State 2, superheated steam with constant entropy with respect to state 1.
c) State 3, saturated liquid at temperature higher than ambient.
d) State 4, mixture with constant enthalpy with respect to state 3.

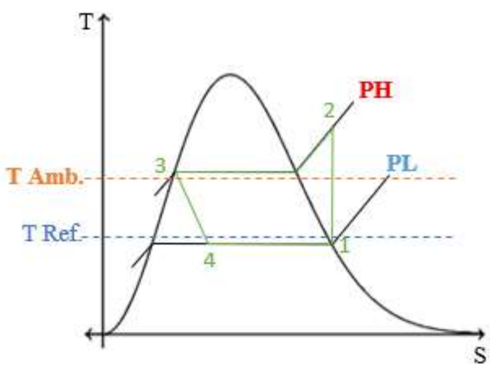

Figure 1 Diagram of the simple compression refrigeration cycle
Source: Own Elaboration

For the realization of the modeling of the cycle parameters such as refrigerant flow, the heat rejected by the condenser, the compressor work and the Coefficient of Performance (COP) are required.

The mass flow of refrigerant acts as a means of transporting heat from one point to another, its function is to absorb heat from the heat loads through the evaporator to subsequently discard this heat to the environment through the condenser, after passing through the compression stage. The mass flow is obtained as:

$$m_R = \frac{Q_L}{h_1 - h_4} \tag{18}$$

Where:
h_1 is the enthalpy at the evaporator outlet
h_4 is the enthalpy at the evaporator inlet

The heat discharged by the condenser is obtained as:

$$Q_H = m_R \ (h_2 - h_3) \tag{19}$$

Where:
h_2 is the enthalpy at the compressor outlet.
h_3 is the enthalpy at the condenser outlet.

The work required by the compressor to increase the pressure of the refrigerant fluid is obtained from the following equation:

$$W = m_R \, (h_2 - h_1) \tag{20}$$

If the thermodynamic states lie within the mixing region in the T-S diagram, the quality X, which varies from 0 to 1, must be determined. The calculation of the quality is obtained from the following equation:

$$X = \frac{h_g}{h_f + h_g} \tag{21}$$

And the enthalpy in the mixed state (h_m), is obtained from the following equations:

$$h_m = \text{X} \, (h_g - h_f) + h_f \tag{22}$$

Where:
h_g is the enthalpy of saturated vapor
h_f is the enthalpy of saturated liquid

The coefficient of performance (COP) for a conventional refrigeration system is obtained from the following equation:

$$COP = \frac{Q_L}{W} \tag{23}$$

Where:
Q_L is the heat or load to be cooled
W is the compressor work

To determine the electrical consumption of the refrigeration system, the efficiency of the compressor must be considered, in this case a hermetic reciprocating compressor suitable for the refrigerant R-290 was selected, having an efficiency that is generally between 75% to 90%. For this analysis an efficiency of 85% is considered, with an operation of 14 hours/day. The electrical energy consumed throughout the day by the compressor is obtained from the following equation:

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$$EE_C = \frac{w*N}{\eta_c} \quad (24)$$

Where:
W is the work required by the compressor
N is the operating time/day
η_c is the efficiency of the compressor

3.5 Integration of the cold room with the refrigeration cycle

Once the calculation of thermal loads, the modeling of the cold room and the refrigeration cycle have been completed, the simulator is integrated. The structure of the simulator design is shown in Figure 2, where the input variables are the dimensions of the chamber, the climatic conditions of the place, the characteristics of the product, the number of people entering and the type of lamps used for lighting the room.

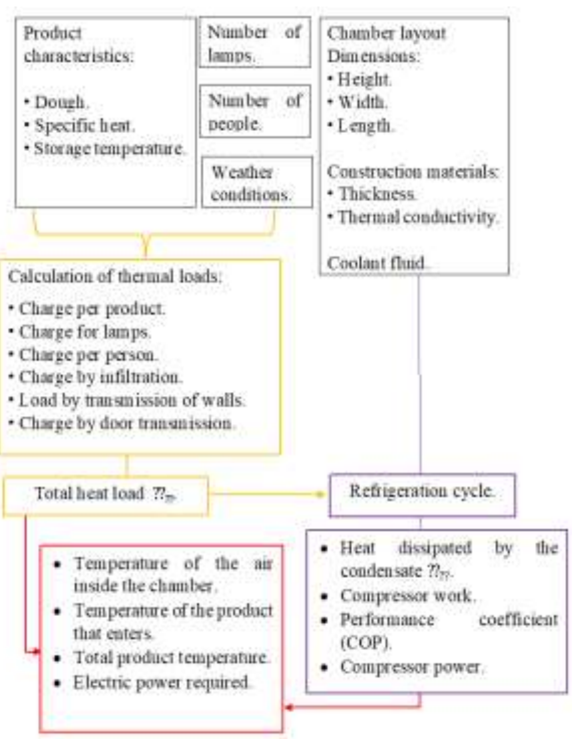


Figure 2 Simulator implementation
Source: Own Elaboration

Subsequently, the simulator calculates the thermal loads, the compressor work and the coefficient of performance (COP) of the system. Additionally, the simulator shows as outputs the temperature of the product entering the chamber, the temperature of the product remaining in the chamber and the electrical energy required.

3.6 Simulator evaluation

For the evaluation of the simulator, a case study must be proposed. In this case, it is proposed to evaluate the preservation of poultry meat, taking into account that the preservation temperature of poultry meat ranges from -1° C to 4° C, with a specific heat of $3.31\frac{kJ}{kg°C}$, and a shelf life of between 8 and 10 days.

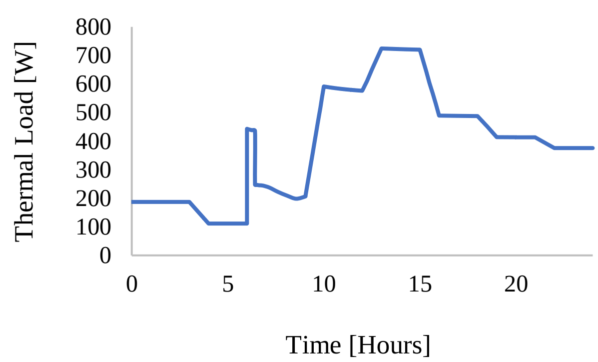
Based on the size of the chamber defined above, which can vary according to needs, a maximum capacity of 500 carcasses was considered. Considering that the storage facility will be located in the municipality of Apan Hidalgo, the climatic conditions of the region are used; atmospheric pressure of 101,325 kPa, with a maximum temperature of 35° C and a minimum of 3° C.

4. Results

The results obtained from the methodology described above are as follows:

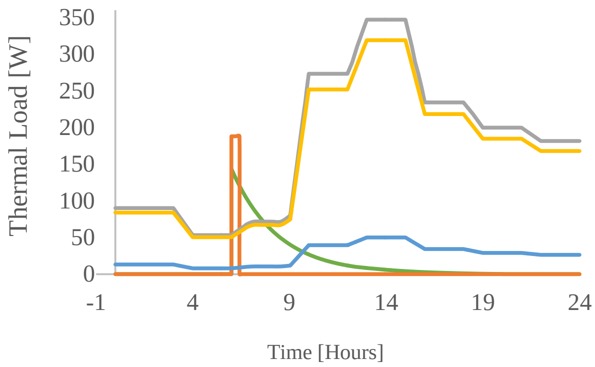
4.1 Simulation of thermal loads

Graph 1 shows the behavior of the total thermal loads throughout an average day, where a maximum load of 724 W at 12:30 a.m. and a minimum of 111 W at approximately 5:00 a.m. is observed.

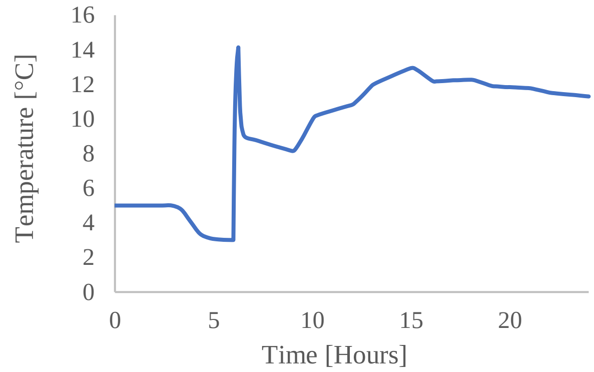


Graph 1 Total thermal load
Source: Own Elaboration

Graph 2 shows the behavior of the thermal loads separately.



Graph 2 Thermal Loads
Source: Own Elaboration



Graph 3a. Air temperature in the chamber
Source: Own Elaboration

The green line represents the thermal load of the product, which enters the chamber at 6:00 hours with a pre-cooling temperature of 10° C, with a cooling time of 8.5 hours and a maximum thermal load of 150 W. The orange line represents the thermal load of the people and lamps.

The orange line represents the thermal load of people and lamps, it is considered that people enter at 6:00 hours and stay 25 minutes and the lamps are kept on during that time, obtaining a thermal load of 188 W.

The gray line shows the thermal load due to infiltration, obtaining 53.3 W as minimum and 347 W maximum.

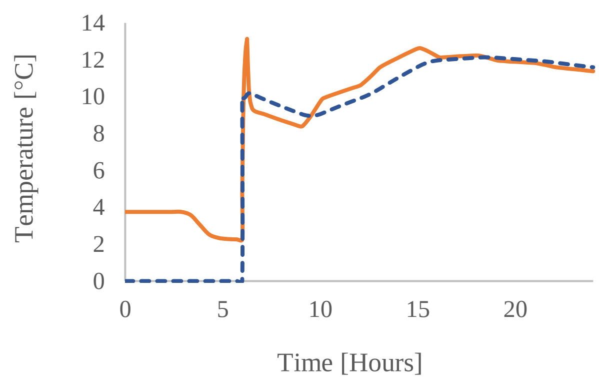
The yellow line shows the thermal load transmission through the walls, obtaining a minimum of 50.3 W and a maximum of 320 W. The blue line shows the thermal transmission load through the door, obtaining a minimum of 7.8 W and a maximum of 50 W.

4.2 Simulation of the interior of the chamber

Graphs 3a and 3b show the behavior of the air and product temperature inside the chamber without refrigeration.

Graph 3a shows the variation of air temperature throughout an average day. A maximum temperature of 14°C is reached at 6:00 a.m., due to the entry of people and product, although this is for a short period of time. The temperature that has the greatest impact on thermal loads is the one obtained due to infiltration through walls, which occurs between 12:00 and 15:00 hours.

Graph 3b shows the temperature of the product throughout the same average day. The solid line represents the variation in temperature of the total meat inside the chamber, which reaches a maximum temperature of 14° C at the time the product is received. The dotted line represents the temperature of the meat entering the chamber at 10° C, increasing its temperature until it stabilizes at approximately 16:00 hours.



Graph 3b Product temperatura
Source: Own Elaboration

4.3 Refrigeration cycle simulation

The refrigeration cycle works from the thermal loads involved in the system. Setting the product storage temperature at 0°C, with a refrigerant mass flow rate of 0.0065 $\frac{Kg}{s}$, the simulator calculates the work required to maintain the storage conditions. A maximum work of 448.1 W is obtained for the extreme conditions, with a coefficient of performance (COP) of 5.39.

Graph 4 shows the heat dissipated by the condensation process Q_H , which reaches a maximum value of 6077 W and a minimum of 5353 W.

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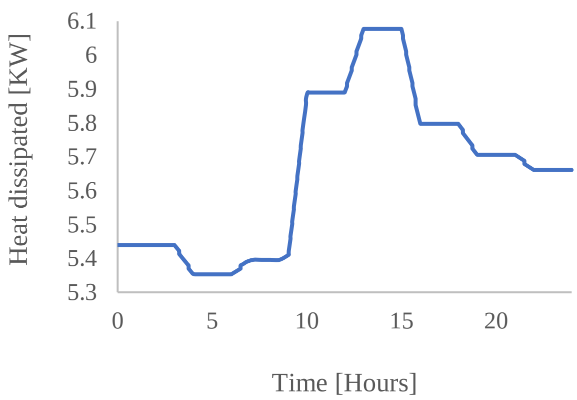
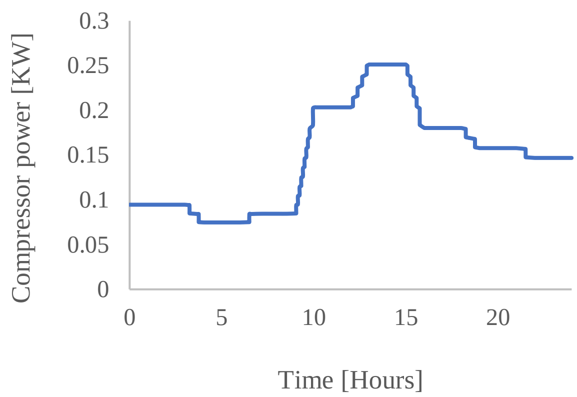


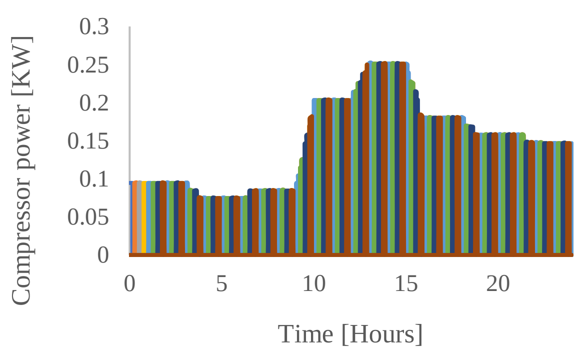
Graph 4 Heat dissipated by the condensation process.
Source: Own Elaboration

Graph 5 shows the work of the compressor during an average day, with a maximum work of 251.2 W at 15:00 hours, and a minimum of 74.77 W at 6:00 hours.



Graph 5. *Compressor work*
Source: Own Elaboration

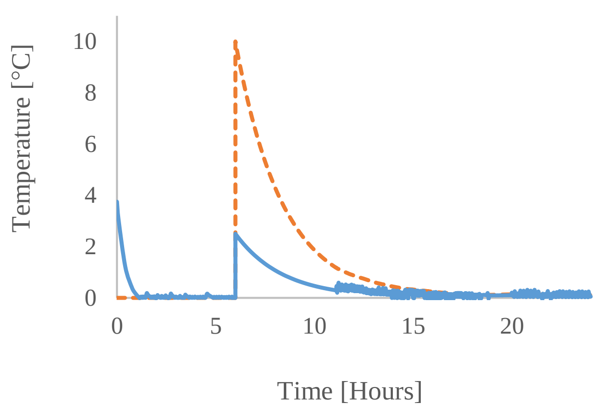
Graph 6 shows the behavior of the refrigeration system cycles in an average day, knowing that the compressor works 14 hours with 25 minutes for every 24 hours of operation, there is a total of 96 cycles in a day.



Graph 6 Cycles throughout the day
Source: Own Elaboration

4.5 Simulation of refrigerated product

The integration of the models of thermal loads, refrigeration cycle and temperature in the chamber, allows us to know the behavior of the temperature of the product to be refrigerated. Graph 7 shows the behavior of the temperature of the meat entering the chamber; the dotted line shows the behavior of the temperature of the product entering the chamber, where it can be observed that it reaches the refrigeration temperature in approximately 8.5 hours. The continuous line shows the behavior of the temperature of the total meat inside the chamber, where an increase in temperature is observed at the time of reception. This increase does not exceed the refrigeration range, which goes from 0° C to 4° C, remaining below 3° C.



Graph 7 Product temperature inside the chamber
Source: Own Elaboration

5. Conclusions

The simulator meets the expectations of evaluating the performance of cold rooms from their operating conditions throughout the day, although for this work an average day of February was considered, the simulator allows evaluating any day of the year, generating as results the behavior of the variables of interest; thermal load, product temperature, waste heat, compressor work, operating time and performance coefficient.

The simulator design considers variable inputs, such as the properties of the construction materials of the chamber, the dimensions of the chamber, and the climatic characteristics of the installation region. It also allows changing the type and quantity of product, the number of people entering the chamber and the lighting. These features make the simulator very flexible, allowing the evaluation of different types of chambers.

The evaluation of the simulator's performance was carried out for the case study referred to in this work, which describes the design of a cold storage chamber for the preservation of chicken installed in the municipality of Apan, Hidalgo. In this evaluation it was verified that the behavior of the conservation temperature shown by the simulator is within the operating range of a real chamber, so it can be said that the design of the proposed chamber is feasible from the thermodynamic point of view.

Regarding energy consumption, considering a hermetic reciprocating compressor with an efficiency of 85% and an operating time of 14.4 hours/day, a maximum power of 448.1 W and an average energy consumption of 3614 Whr/day were obtained, which indicates that the chamber design is also feasible from the energy point of view.

Currently it is intended that any energy system is sustainable, and a cold room is no exception, so it would be desirable that the simulator in addition to assessing the energy feasibility also verify whether the design of the chamber can be sustainable. Therefore, it is considered as future work to integrate a module to the simulator to determine the economic feasibility of generating the work of the compressor through solar energy.

It is worth mentioning that the purpose of this simulator is to evaluate the energy feasibility of a cold room design, using theoretical models obtained from general physical laws, so the results generated should be considered ideal. To improve the performance of the simulator, the input variables should be as close to reality as possible.

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Temperature control based on Fuzzy Logic using Maximum Center Method

Control de la temperatura basado en la lógica difusa mediante el método del centro máximo

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Abstract

There is a close relationship between crop growth and the control of environmental variables, as well as irrigation and fertilizers supplied. This article presents a system for collecting a greenhouse temperature, capable of acting in the opening or closing window system as a regulator of this environmental variable. Controlling the temperature acting on the opening or closing of the windows is convenient, since it does not require additional fuel, resulting in an economical alternative. Regarding control algorithm, Fuzzy Logic was used as a correction temperature technique. The proposal can be a good option for greenhouses that are not automated yet, saving costs by moving from human-assisted monitoring to automatic temperature monitoring.

Diffuse control, Temperature control, Protected agriculture

Resumen

El crecimiento de los cultivos en sistemas de agricultura protegida está en función del control de las variables ambientales, así como por el riego y fertilizantes suministrados. En este artículo se presenta como propuesta un sistema para la recolección de temperatura de un invernadero, capaz de actuar en la apertura o cierre de las persianas como regulador de esa variable ambiental. Controlar la temperatura controlando la apertura o cierre de las ventanas resulta conveniente dado que no requiere combustibles, resultando en una alternativa económica. Respecto al control, se utilizó la Lógica Difusa como tecnica para la corrección de la temperatura. La propuesta puede resultar de interes para una gran cantidad de invernaderos que aún no están automatizados, ahorrando costos al pasar de una supervisión asistida por humanos a una supervisión de la temperatura automática.

Control difuso, Control de temperatura, Agricultura protegida

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Introduction

The greenhouses development, in the context of sustainable agriculture, is so far the most promising alternative to meet food needs. As mentioned by Escamilla *et al*., (2020), protected agriculture aims to improve the quality and quantity of the product, minimizing production costs (Xing *et al*., 2017). The objective is achievable if the environmental conditions information is known in detail. On the other hand, an efficient use of resources such as water and energy are necessary, because they are scarce and expensive (Hemming *et al*., 2019).
In the literature, some technological proposals can be found based on monitoring and control greenhouse environmental conditions.

For Vimal and Shivaprakasha (2018), Widyawati et al., (2020), some parameters such as temperature, humidity, light intensity, soil moisture, allow monitoring greenhouse environmental conditions. Hemming et al., (2019) mentions some applications of Artificial Intelligence algorithms applied to irrigation and environment control, in vegetable harvest. For Goap et al., (2018), other technologies can be used, such as machine learning (ML) for the control of irrigation management systems.

Fuzzy logic is a popular and widely Artificial Intelligence algorithm applied in control systems. Marimin and Mushthofa (2013), describe automatic control systems and decision support systems, as a Fuzzy Logic application scope.

In this research work you will find the development of a greenhouse temperature control system, based on Mamdani fuzzy control architecture. In the next section, a review of related research works is provided, following with the sensing temperature mechanism, as well as the control algorithm description. Finally, the conclusions and future work.

Previous work

Due to the complexity that represents the development of environmental variables control system, based on growers experience heuristic rules, it is possible to find several previous works with advantages and disadvantages of the different techniques, applied to this kind of solution (Galvan *et al*. 2012).

In his classification, control systems were divided in conventional and optimal control. Conventional control consisting of theories that attempt to control the environment of a greenhouse, reducing the set points deviation between the interest variables and the measured values to zero.

On / Off, Proportional Integral Derivative Controller (PID) and some Artificial Intelligence paradigms such as Artificial Neural Networks (ANN), Fuzzy Logic-based Systems (FLS), Genetic Agorithms (GA), among others, can be conventional control examples.

On the other hand, in Optimal Control, aspects such as greenhouse behavior, actuator capacities, energy consumption and mainly the crop response are considered as input parameters of the control process. Expert systems and the Predictive Control Model (MPC) are some of the most common techniques. However, Artificial Intelligence based techniques can also be considered as an optimal control when considering the crop response as input parameter.

Systems based on Fuzzy Logic control have achieved important results in greenhouses temperature control field. For this, it is necessary to have reliable information about system behavior, as well as a correct abstraction to create rules based on heuristic and empirical knowledge from the producer's experience. In addition, fuzzy control can be robust and cheap (Passino *et. al*., 1998).

Castañeda *et. al*., (2006), propose an interesting Fuzzy Logic application to controlling climatic variables, using an FPGA to execute low-level tasks, such as the monitoring of climatic variables and the operation of actuators, like heaters and windows to control the internal greenhouse temperature.

His project uses a data acquisition module, one analog/digital conversion module, and a third fuzzy logic FPGA module. Gómez *et al*. (2011) presents fuzzy control proposal over FPGA for greenhouse fertigation control. This project presents the modularization of its system, emphasizing the potential to save significant amounts of water and nutrients compared to conventional systems, as a product of diffuse control.

Additionally, they emphasize some characteristics of fuzzy control, mainly its adaptability, simplicity, and ease of implementation, making it an excellent tool for its application in the optimization of fertigation systems.

Finally, more studies can be found in the literature that present advantages of Fuzzy Control over traditional control systems in greenhouse automation (Ödük y Allahverdi, 2012).

Sensorization

The design and conditioning of a prototype was made for the automation of a greenhouse with the Intel Galileo and Arduino microcontroller. The first prototype is the automatic control of opening and closing of greenhouse windows that is carried out through a 24V, 500W, 1800RP motor that was implemented with the PWM (SHT-146), which is a reversible control and of speeding for 6V-30V, 6A motors (see figure 1).

Figura 1 Motor, automatic control prototype, and capacitive proximity sensors

The second prototype consists in the conditioning and install of two capacitive proximity sensors (E2K-C25MF1) strategically located for detect the closing and total opening greenhouse windows.

These prototypes keep a Wireless communication trough Xbee with a relative humidity and temperature probe (HMP60-Vaisala) located in the center of the greenhouse, for monitoring and optimize the relative humidity of the environment. The sensorization for the shutter opening and closing control, as well as the humidity and relative temperature control of the greenhouse, is energized with a solar charge control (EPRC-12/24V 10Amp) for efficient energy consumption. It was developed a sensorization module that consist in two parts:

Transmitter

A first transmitter module, that consist in an Arduino Uno microcontroller, initially equipped of a temperature sensor Keyes DS18B20, responsible for acquiring the temperature, recording any variation in the greenhouse (see figure 2). Also, a Xbee microcontroller was installed, which provided the module with Wireless communication, in such a way that when temperature changes are registered, they are sent to a second receiver module.

The wireless communication provided by the XBee was a restriction given the distance from the center of the greenhouse to the corners, which is where the manual mechanisms for opening-closing the windows are located. The energy supply of this transmitter module is in charge of a solar cell.

Vaisala HMP60 probe calibration. The probe sends voltage as a product of the temperature and humidity reading. The algorithm was developed to convert the values expressed in voltage by the probe to temperature.

The readings obtained from the Keyes DS18B20 sensor, Vaisala probe and an analog thermometer were verified, with a difference of less than half a degree centigrade between the three readings. Once the input was verified, the Keyes DS18B20 sensor used for prototyping was replaced by the Vaisala probe, for industrial use (see Figure 3).

Figura 2 Transmitter. Notice an Arduino Uno microcontroller, powered by power from a solar cell. See the cable that goes up, corresponding to the Vaisala probe, which does the temperature measurement.

Figura 3 Vaisala probe calibration with respect to the thermometer they have in the greenhouse

Receiver

The receiver is integrated by a Galileo Generation 2 microcontroller with Yocto operating system, the temperature readings arrive remotely through an Xbee microcontroller (see figure 4). Limits configuring. The Galileo microcontroller has a web server and some scripts developed in Python, which allow you to configure the temperature limits from a web application.

Lower limit defines the minimum allowable temperature in which the plant can be without stress. Upper limit defines the maximum temperature Ideal, defines the optimum temperature for the type of crop.

The objective of the limits is to control the opening and closing of the windows, according to the temperature readings that arrive. An austere diffuse temperature controller will be in charge of making the temperature as close as possible to the ideal temperature.

Basically, as you get closer to the maximum and minimum limits, the temperature correction will be more frequent. The windows have sensors that allow to know if the window is completely open or completely closed, in which case, the motor no longer operates the window only in that sense.

Figura 4 Galileo receiver. The ethernet interface sends the measurements to a remote server

Control design

The blinds' control is a control system based on fuzzy logic and is conformed by a closed loop controller of the Proportional-Derivative type, with two inputs and one output. The physical inputs of the system are the ideal temperature and the current temperature, concerning of the inference machine, the inputs are the error and the derivative of the error. As a result, the inference machine generates the opening percentage that the blinds will have. The fuzzy inference machine is made up of three essential parts: Diffusion, Reasoning or IF-THEN Fuzzy Rules and defuzzification.

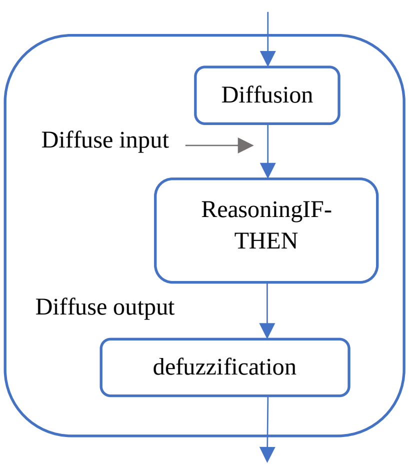

Figura 5 Fuzzy inference machine

Diffusion is a process in which physical variables are converted into fuzzy inputs, the value of the variables is evaluated, and they are assigned a degree of membership in the fuzzy sets defined by the designer. To carry out this process, the membership functions of fuzzy sets are used.

The reasoning within a fuzzy inference machine is responsible for evaluating the rules proposed by the designer. The rules relate the fuzzy inputs and generate the fuzzy output; These rules are called "Fuzzy Rules" later this fuzzy output is converted into a real output through the de-diffusion process, with the real output the system will perform the desired action.

Mamdani's inference machine

For this project the Mamdani inference was used (Lee, 1990; Tamir et. al., 2015).

Mamdani's fuzzy rules:

IF (X_1 is A AND X_2 is B) THEN (U_1 is C)

Where X_1 y X_2 are the input variables, *A* y *B* are the membership functions input, U_1 is the fuzzy output and *C* is the output membership function.

The first part of the statement *"IF (X_1 is A AND X_2 is B)"* is known as antecedent and *THEN (U_1 is C)* is the consequent.

As advantages it can be determined that it is intuitive, widely accepted, adapted to the incorporation of knowledge and experience.

Defuzzification is the conversion of the diffuse output of the inference machine to an output variable, that is, the result obtained from the rules within the inference machine will be translated into a real physical signal for our control system.

For defuzzification there are several methods, it is important to choose the right one.

a) Centroid method

The Center of Gravity or Center of Area method is the most used of the defuzzification methods and its expression is as follows:

$$Z = \frac{\int \mu(u) * ui \, dc}{\int \mu(ui) \, dc}$$

Where $\int$ is the algebraic integral; ui is the typical value of each function and $\mu(ui)$ is the membership value in this function.

For this method, it is necessary to use a microcontroller that performs the most accurate and efficient calculations since the formula contains integrals, so the processing time would increase. So, it is more expensive.

b) Center of Maximum Method (COM)

In this method, the fuzzy set of the output variable and its membership values are considered, such that the sum of the membership values is equal to one, $\sum \mu(ui) = 1$, where ui are the typical values of each membership function that are part of the output set. The membership values are weighted with the typical values of each function.

The actual output is obtained with the expression:

$$Z = \frac{\sum_{i=1}^{n} \mu(ui) * ui}{\sum_{i=1}^{n} \mu(ui)}$$

Where u*i* is the typical value of each function. *μ(ui)* is the membership value in this function.

The COM it is an efficient method, if symmetric functions are used, also it can obtain real output values using limited computational resources. This method was used in this project because of its low cost.

Input

Regarding the controller, its inputs are given by the *temperature error* obtained from the greenhouse temperature. (Ideal temperature - Current temperature) and the *Derivative of the temperature error (dE / dt)*, which is the difference between the current error and the previous one.

The fuzzy inputs, composed of the Temperature Error and the Temperature Derivative, they are processing with a diffusion process, assigning membership values.

With a range of 20 to 44 degrees, a Lambda function, three triangular functions, and a gamma were defined.

Very Positive (MP) Lambda

$$L(u; 20{,}26) \begin{cases} 1, if\ u \le 20; \\ \dfrac{26-u}{26-20} \quad , if\ 20 \le u \le 26; \\ 0, if\ u > 26. \end{cases}$$

Positive (P) Triangular

$$\Lambda(u; 20{,}26{,}32) \begin{cases} 0, if\ u \le 20; \\ \dfrac{u-20}{26-20}, if\ 20 \le u \le 26; \\ \dfrac{32-u}{32-26}, if\ 26 \le u \le 32; \\ 0, if\ u > 32. \end{cases}$$

Zero (Z) Triangular

$$\Lambda(u; 26{,}32{,}38) \begin{cases} 0, if\ u \le 26; \\ \dfrac{u-26}{32-26}, if\ 26 \le u \le 32; \\ \dfrac{38-u}{38-32}, if\ 32 \le u \le 38; \\ 0, if\ u > 38. \end{cases}$$

Negative (N) Triangular

$$\Lambda(u; 32, 38, 44) \begin{cases} 0, if\ u \le 32; \\ \dfrac{u-32}{38-32}, if\ 32 \le u \le 38; \\ \dfrac{44-u}{44-38}, if\ 32 \le u \le 44; \\ 0, if\ u > 44. \end{cases}$$

Very Negative (MN) Gamma

$$\Gamma(u; 38{,}44) \begin{cases} 0, if\ u \le 38; \\ \dfrac{u-38}{44-38} \quad , if\ 38 \le u \le 44; \\ 1, if\ u > 44. \end{cases}$$

The *Error´s derivative* has a range between -1 to 1, where -1 indicates that the greenhouse temperature is cold compared to the ideal temperature, therefore, the blinds must remain closed. On the contrary, 1 indicates that the temperature has risen, so the blinds must be open.

Negative Derivative (DN) Lambda Function

$$L(u; -1, -0.5) \begin{cases} 1, if\ u \le -1; \\ \dfrac{-0.5-u}{-0.5+1} \quad , if -1 \le u \le -0.5; \\ 0, if\ u > -0.5. \end{cases}$$

Zero Derivative (DC) Triangular Function

$$\Lambda(u;-0.5,0,0.5)\begin{cases} 0, if\ u < -0.5; \\ \dfrac{u+0.5}{0+0.5}, if -0.5 \le u \le 0; \\ \dfrac{0.5-u}{0.5-0}, if\ 0 \le u \le 0.5; \\ 0, if\ u > 0.5. \end{cases}$$

Positive Derivative (PD) Gamma Function

$$\Gamma(u;0.5,1)\begin{cases} 0, if\ u < 0.5; \\ \frac{u-0.5}{1-0.5} \quad , if\ 0.5 \le u \le 1; \\ 1, if\ u > 1. \end{cases}$$

The fuzzy rules from Mamdani's architecture, generated from the field experience that the inference machine follows, can be seen in a fuzzy memory.

It is necessary to mention that the outputs with (*) are indicated in this way, because the case of belonging between the functions of the Temperature Error and the derivative of the Error will never occur. In the case of output N, it is presented in this way, because no movement is generated, since the set point (desired temperature) is reached.

Temperature Error						
MN	N	C	P	MP		
*A	*AB	CA	CB	C	DN	Error's derivative
*A	AB	N	CB	*C	DC	
A	AB	AA	CA*	*C	DP	
Expected output						

Tabla 1 Fuzzy memory

The defuzzification output can be presented in figura 6.

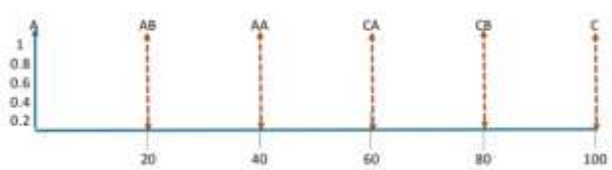

Figura 6 Output of the Fuzzy Control, percentage of opening / closing of blinds

Description of fuzzy control outputs using singleton functions**:**

$$\text{Open (A)} = \mu(u) = \begin{cases} 1, si\ u = 0 \\ 0, si\ u \neq 0 \end{cases}$$

$$\text{Low Open (AB)} = \mu(u) = \begin{cases} 1, si\ u = 20 \\ 0, si\ u \neq 20 \end{cases}$$

$$\text{High Open (AA)} = \mu(u) = \begin{cases} 1, si\ u = 40 \\ 0, si\ u \neq 40 \end{cases}$$

$$\text{High Close (CA)} = \mu(u) = \begin{cases} 1, si\ u = 60 \\ 0, si\ u \neq 60 \end{cases}$$

$$\text{Low Close (CB)} = \mu(u) = \begin{cases} 1, si\ u = 80 \\ 0, si\ u \neq 80 \end{cases}$$

$$\text{Close (C)} = \mu(u) = \begin{cases} 1, si\ u = 100 \\ 0, si\ u \neq 100 \end{cases}$$

Applying the COM method for inverse diffusion, starting from the maximums of the Error Derivative and the Temperature Error:

$$Z = \frac{\sum_{i=1}^{n} \mu(ui) * ui}{\sum_{i=1}^{n} \mu(ui)}$$

The Z value that represents the percentage of opening of the greenhouse blinds. Figure 7 shows a Z output of the control code, for a temperature between (34-36) Celsius degrees, with an average output opening percentage between (25-26)%.

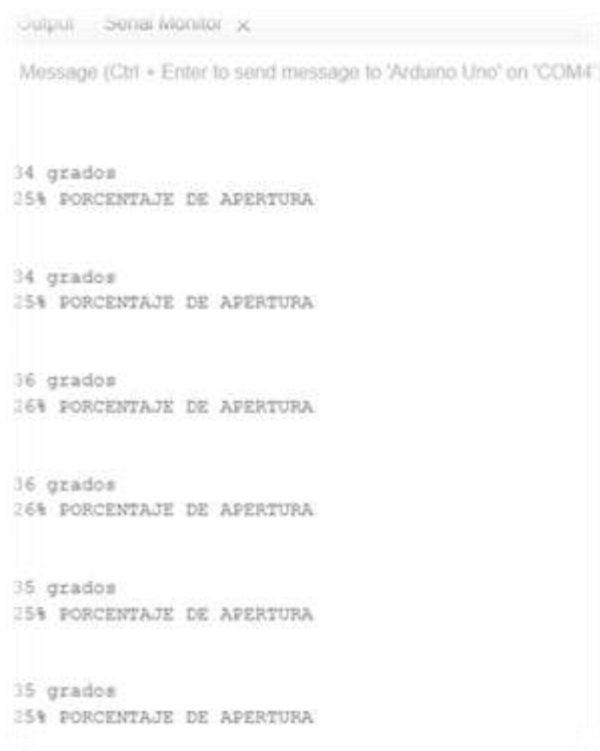

Figura 7 Results Obtained in the Serial Monitor

Results

The control has been tested in a mechanical prototype (see figure 1), where the blinds opening/closing has been compared according to the opening percentage generated by the control code with Fuzzy Logic.

Agradecimiento

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Conclusiones

This article proposes an investigation to provide technology to a rustic greenhouse. The fuzzy logic control system presented in this article aims to explain the implementation process, which can be used to solve similar problems.

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Data acquisition module for the operation of the Neural Network for crop rotation and soil analysis in a Greenhouse

Módulo de adquisición de datos para el funcionamiento de la Red Neuronal para la rotación de cultivos y análisis de suelo en un Invernadero

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Abstract

Currently, with the technological advances applied in various sectors, they have changed the way they operate in the control of their processes. In the agricultural sector, the automation of processes increases productivity and improves the quality of products. In the production crops using greenhouses, these protect the different plants from excess cold at certain times of the year, allowing control of temperature, humidity and other environmental factors that favor plant growth. This project describes the function of the data acquisition module, which aims to obtain or generate values of the variables of humidity, ambient temperature and soil pH, through electronic devices such as sensors and the arduino for the operation of the neural network for crop rotation and soil analysis. Through an interface, it is linked to the expert system that shows the values and results generated by the neural network on the ideal type of crop to plant. For the development of the project, the model in Prototypes was used

Data acquisition, Sensors, Soil analysis

Resumen

En la actualidad, con los avances tecnológicos aplicados en diversos sectores, han cambiado la forma en cómo operan en el control de sus procesos. En el sector agrícola, la automatización de los procesos aumenta la productividad y mejora la calidad de los productos. En la producción de cultivos bajo invernadero, estos protegen, las diferentes plantas del exceso de frío en ciertas épocas del año, permite el control de la temperatura, la humedad y otros factores ambientales que favorecen el crecimiento de las plantas. Este proyecto describe el funcionamiento del módulo de adquisición de datos, que tiene como objetivo obtener o generar información de los valores de las variables de humedad, temperatura del ambiente y pH del suelo, a través de dispositivos electrónicos como los sensores y el arduino para el funcionamiento de la red neuronal para la rotación de cultivos y análisis de suelo. Mediante una interfaz, se enlaza al sistema experto que muestra los valores y los resultados que genera la red neuronal sobre el tipo de cultivo idóneo a sembrar. Para el desarrollo del proyecto se utilizó el modelo en Prototipos.

Adquisición de datos, Sensores, Análisis de suelo

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Introduction

As part of the process of adaptation of society to technological changes, greenhouse agriculture has not been an exception to these changes, it has led to integrate with technology that allows improving and transforming the cultivation processes. This paper describes the operation of the data acquisition module, this module is part of the neural network project for crop rotation and soil analysis in a greenhouse based on the expert system, which was developed with the objective of supporting the farmer in making a decision on the optimal type of crop to plant in the greenhouse, to improve the production of greenhouse crops through an analysis of soil (pH) and environment (humidity and temperature). With the analysis, the ideal crop to be planted is determined, thus the risk of production loss is considerably reduced, resulting in increased production and improved product quality.

Therefore, this article describes the data acquisition module, the electronic devices used and the circuit design; the development methodology through the prototype model and the description of the stages of the first prototype. Subsequently, the functionality of the soil analysis and measurement interfaces, the results, acknowledgements, conclusions and bibliographical references are explained.

Data acquisition module

For the neural network for soil analysis in the crop rotation in a greenhouse to work properly, it is necessary that it is supported by a data acquisition module; the data obtained are used for the training phase of the neural network, in addition to predicting whether the soil and environmental data are favorable for the cultivation of plants of a specific family.

The results of the module are: The most optimal crop type to be planted, the optimal moisture values and the ranges in which they should be, the optimal temperature for the crop type to be planted and the corresponding family.

For data acquisition, it refers to the part in charge of acquiring data from sensors; it is a collection of software and hardware that allows measuring or controlling the physical characteristics of something in the real world such as voltage, temperature, sound level, among others.

Devices for the data acquisition module

The following devices were used in the design of the data acquisition module

1. Dht11 (temperature and humidity sensor).
2. Arduino Uno
3. Protoboard
4. Ph-4502C (pH sensor)
5. Electrode

Sensors

They are electronic devices with which we can interact with the environment, they provide us with information of certain variables that surround us, to be able to process them and thus generate orders or activate a process. The variables depend on the type of sensor and can be: temperature, light intensity, distance, acceleration, humidity, pressure, pH. They are used in different areas such as agriculture, mobile telephony, medicine, automotive or industrial automation processes (Serna R.A., Ros G.F.A. and Rico N.J. C. 2010).

For this project, the Dht11 digital sensor was used to monitor temperature and relative humidity. It integrates a capacitive humidity sensor and a thermistor to measure the surrounding air, and displays the data via a digital signal on the data pin. It is used in academic applications related to automatic temperature control, air conditioning, environmental monitoring in agriculture and more (Suarez, 2019), see Figure 1.

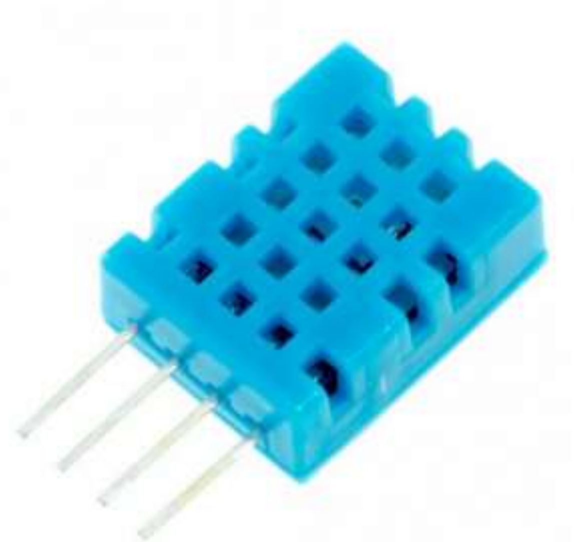

Figure 1 Dht11 sensor

PH-4502C sensor

Device that allows to measure the PH with the help of a probe that takes the reading (E201 electrode) by means of the BCN connector. It is useful if you need to measure the PH.

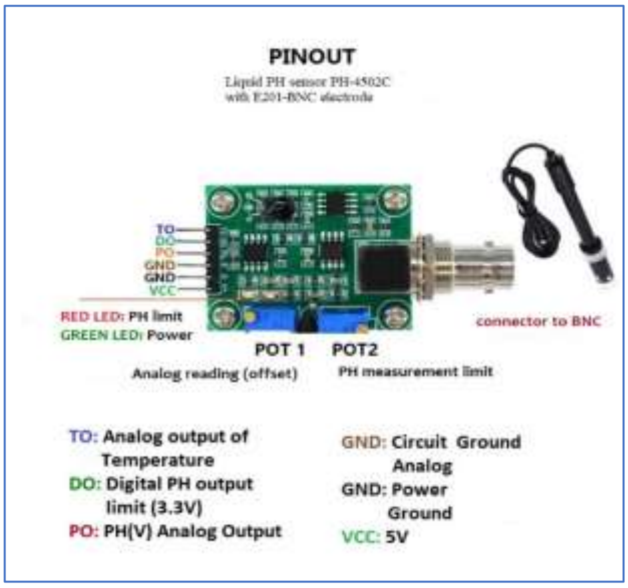

Figure 2 PH-4502C sensor

Arduino

It is considered a development platform based on a free hardware electronic board that incorporates a reprogrammable microcontroller and a series of female pins. These allow to establish connections between the microcontroller and the different sensors and actuators in a very simple way. One of the most important features of this platform is the possibility of building the boards at home since its components can be found in electronic component stores and using a Protoboard or an easy to produce low cost printed circuit board. For the programming of the Arduino we used the processing programming language.

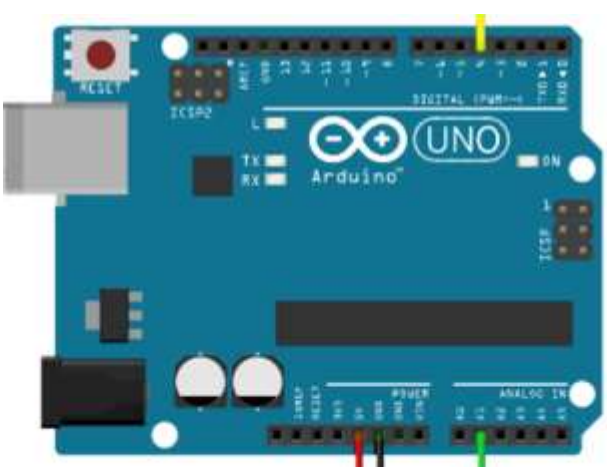

Figure 3 Arduino one

Protoboard

It is a test board that allows interconnecting electronic elements without the need to solder components. This facilitates the assembly of electronic circuits or systems. It is normally used to test electronic circuits. If the test is satisfactory, the circuit is designed on a copper plate and soldered to avoid the risk of disconnecting any component. If the test is not satisfactory, it is easy to change connections and replace components.

The Protoboard has three easily identifiable parts: the center channel, the tracks, and the buses. Center channel, as shown in Figure 4.

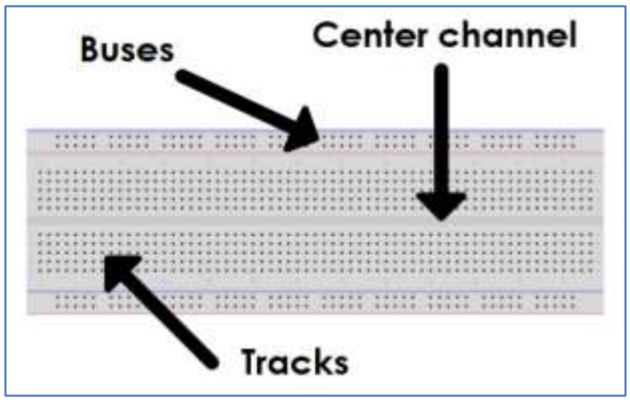

Figure 4 Parts of the Protoboard

Factors that influence crop growth

For Fernandez, (2014), mentions that it is necessary to know the conditions that favor or limit plant development, so that we provide plants with the optimal conditions for their growth and production.

The basic requirements for plant development regardless of the cultivation system are the following:

a. Humidity

The degree of humidity of the environment will condition to a great extent the transpiration of the plant and, therefore, the consumption of water. An adequate level of ambient humidity allows photosynthesis to take place in plants. It also allows plants not to evaporate and transpire as much water through their stomata, which in turn means that the plant loses less water and is not so dependent on irrigation.

b. Temperature

This is a growth factor of the first magnitude, and consequently is one of the most important limiting factors in the practical development of crops, since it influences all the basic processes carried out by plants (germination, flowering).
Maintaining a balanced temperature in crops is essential to favor the correct development of the plant, as it influences its growth and productivity in the harvest. When cultivating, it is important to know what temperature conditions are necessary for each plant, as they vary depending on the species.

c) Soil

The soil is the top layer of the earth where the roots of the plants develop. This layer is a large reservoir of water and food from which the plants take the necessary quantities to grow and produce crops. Good soil is essential for a good harvest. The soil must have all the nutrients necessary for plant growth, and a structure that keeps the plants firm and upright. The soil structure must ensure sufficient air and water for the plant roots, but must prevent excess water by good drainage.

One of the main characteristics of soil is pH, which is a measure of the acidity or alkalinity of the soil, and affects the absorption of nutrients by plants.

The pH can vary from 0 to 14 and according to this scale, soils are classified as follows:

Type of soil	PH
Acid soil	Less than 6.5
Neutral soil	6.6 – 7.5
Basic soil	Greater than 7.5

Table 1 PH in soils

Development Methodology

For the operation of the two modules the Prototyping model was used, this model aims at the direct participation of the client in the construction of the required software, and serves as a mechanism to identify and define the software requirements, through an iterative process (Pressman, 2010, p. 37). Figure 5 shows the stages: communication, rapid plan, rapid modeling and design, prototype construction, deployment, delivery and feedback.

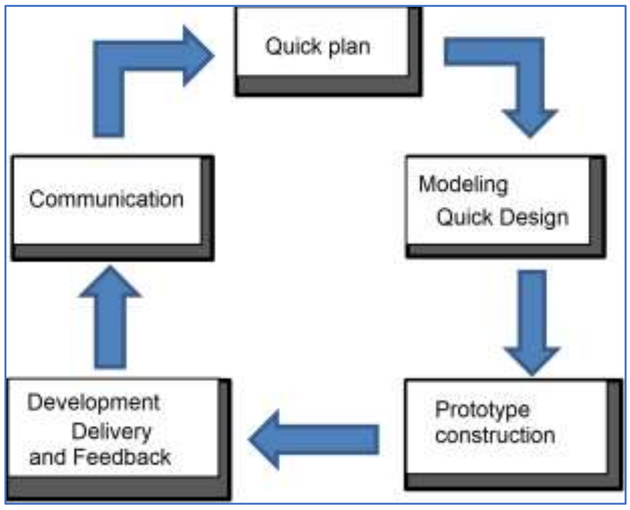

Figure 5 Adapted Prototype Model
Source (Pressman, 2010, p. 37)

First Prototype: The data collection module is created, the results of which will be used in the training phase of the neural network, in addition to predicting whether the soil and environmental data are favorable for harvesting plants of a specific family. In this work, emphasis will be placed on the data acquisition module.

Development of the stages

– Communication stage, in this first stage it is required to obtain the data of the environment and soil, in a fast and efficient way, for this pH, humidity and temperature sensors will be used.
– The Rapid Plan stage. In this stage, the use case technique was used to model the requirements of the data acquisition module. Figure 6 shows a use case for obtaining data from the Dht11 temperature and humidity sensor and the pH-4502C sensor.

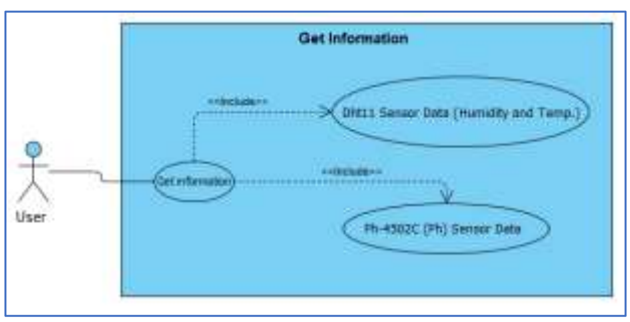

Figure 6 Sensor data collection use case

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Figure 7 shows its use case table.

No.	2
Use case:	Sensor data dht11 (Humidity and Temperature)
Actor:	User
Description:	The Arduino program displays the values obtained by the sensor on the screen.
Validation	The sensor must be connected.

Figure 7 Temperature and humidity sensor use case

– In the Rapid Design Modeling stage, the sequence diagrams and the circuit diagram design were designed. See figure 8.

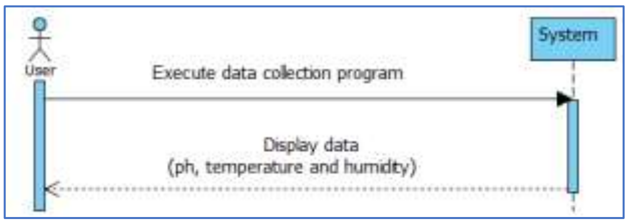

Figure 8 Sequence diagram: Data acquisition

Circuit diagram

Figure 9 shows the design of the circuit diagram to obtain data through the Dht11 sensor to obtain the values of temperature and humidity of the environment, in addition to the Ph-4502C sensor for pH values.

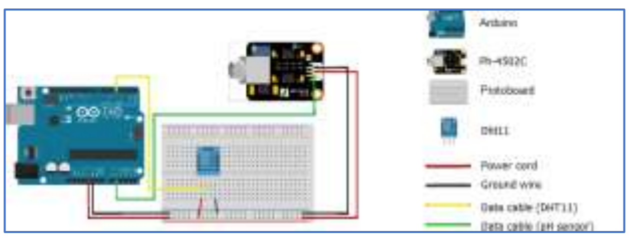

Figure 9 Circuit diagram

– Prototype construction stage, the circuit is built, as shown in Figure 10.

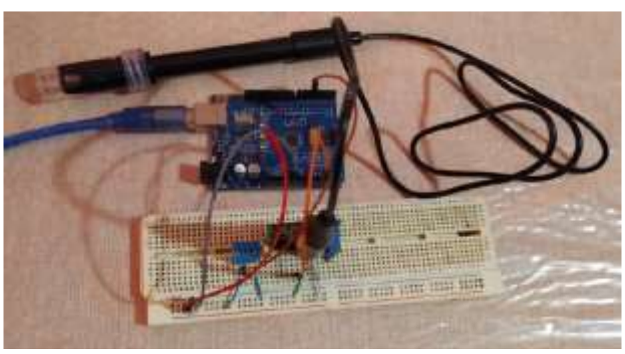

Figure 10 Circuit construction

– Deployment, delivery and feedback stage. In order to perform the soil analysis tests and check correctly, it is necessary to follow the steps below:

1. Make a solution with two portions of water and one portion of soil in a container.

2. Shake the solution and let it stand for at least 15 minutes.

3. Clean the electrode nozzle with a dry and soft cloth to remove any existing solution as it may contaminate the sample.

4. After the 15 minutes of waiting, insert the electrode nozzle into the solution.

5. Run the data acquisition program.

The final design of the data acquisition module is shown below.

Figure 11 Final design of the data acquisition module

Results

The results obtained from the Data Acquisition module are shown below, describing the functionality of the Soil Analysis and Measurements options. To start, the user must log into the system with the user name and password. See Figure 12.

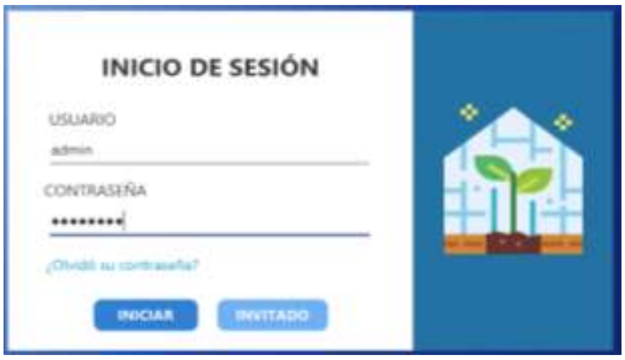

Figure 12 System access screen

A. Soil Analysis Interface

Select from the main menu the soil analysis option, as shown in Figure 13.

Figure 13 Main menu of the expert system

1. When clicking on the soil analysis option, the system first validates that there is a connection to the data acquisition device. If there is no connection, it sends a message as shown in the following message.

Figure 14 Connection problems

2. Once the connection has been validated, click on the Take measurements button.

Figure 15 Soil analysis module

3. It shows the following message, that measurements are being taken from the data acquisition module in real time, as shown in Figure 16.

Figure 16 Temperature, humidity and pH measurement taking message

Results

Figure 17 shows the values obtained from the data acquisition module:

– PH: This text field shows the PH of the soil obtained by the data acquisition device.

– Humidity: This field shows the humidity of the environment obtained by the data acquisition device.

– Temperature: This field displays the temperature of the environment obtained by the data acquisition device.

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Figure 17 Values obtained

When the data is obtained, the type of previous family that was sown must be selected, in this case the Solanaceae family is chosen, when clicking on the CALCULATE button, the neural network begins to perform the analysis and shows as a result the most optimal type of crop to be sown.

B. Measurements *Interface*

When clicking on the Measurements option, the system sends a message that the current measurements of temperature and humidity of the environment are being taken from the data acquisition module, see figure 18.

Figure 18 Measurements module

The measurements show in real time the temperature and humidity values, see Figure 19.

Figure 19 Current temperature and humidity measurements

Acknowledgments

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We are grateful for the collaboration and dedication of the authors of the article who participated with responsibility in the research until the results presented were obtained; the objective of this research is to be able to disseminate the findings to the academic community and the general public about the work being carried out at the Institution.

Conclusions

The evolution of technologies allows the automation of processes and communication between different electronic devices for data acquisition. Samples from the real world to generate data that can be manipulated by a computer.

The development of the data acquisition module in this project was indispensable since it allows to generate and obtain real time values of temperature and humidity variables and soil PH for the execution of neural network for crop rotation and soil analysis in a Greenhouse, since it provides alternatives on the type of crop to plant through crop rotation, an alternative technique for the types of plants that are grown in the same place with the intention of not developing diseases that affect a specific family of crops and prevent the soil from being exhausted.

Finally, the communication capacity of intelligent devices with electronic circuits opens a range of possibilities for future work, as they can be applied in home automation, data control, industrial security and others, which help in improving the social problems facing society today.

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Structural analysis, simulation and validation as a strategy for product design

Análisis, simulación y validación estructural como estrategia para diseño de producto

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Abstract

In the process of developing products to meet specific needs or requirements, it is crucial, in terms of functionality, to achieve the interaction of two strategies: on the one hand, end-user feedback and, on the other hand, architectural optimization by applying finite element analysis (FEA). Seeking the consolidation of a new product and identifying opportunities for improvement, this article presents the results of an FEA study applied to a multicultivator (case study) in which the premises were: 1) validation of the design proposal; 2) evaluation of areas detected as "critical"; and 3) optimization of geometry to reduce weight and manufacturing costs. The procedure used to structure the design of the multicultivator under the approaches of architecture validation, production quality improvement and cost reduction is also presented in a simplified manner.

Design, Functionality, Optimization

Resumen

En el proceso del desarrollo de productos destinados a cubrir necesidades o requerimientos específicos es determinante, hablando en términos de funcionalidad, lograr la interacción de dos estrategias: por un lado, la retroalimentación del usuario final y por el otro, la optimización de arquitectura aplicando análisis de elemento finito (FEA). Buscando la consolidación de un nuevo producto e identificando oportunidades de mejora, en el presente artículo se presentan los resultados de un estudio de FEA aplicado a un multicultivador (caso de estudio) en el cual se tenía como premisas: 1) validación de la propuesta de diseño; 2) evaluación de zonas detectadas como "críticas"; y 3) optimización de geometría para reducir peso y costos de manufactura. Se presenta también, de manera simplificada, el procedimiento utilizado para estructurar el diseño del multicultivador bajo los enfoques de validación de arquitectura, mejora de calidad en producción y reducción de costos.

Diseño, Funcionalidad, Optimización

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1. Introduction

To design is to establish and define pertinent solutions and structures for problems that have not been solved before or new solutions proposed in a different way for problems that have been previously solved. Design is part science and part art. The scientific part of design can be learned through the different philosophies, methodologies and tools that exist and that try to systematize this task. However, the art part of the design process, today, cannot be taught systematically. Therefore, many designers argue that the only way to learn the art part of design is by designing (Evbuomwan et al, Kaspar et al, Tomiyama et al, Tran *et al*).

FEA is currently a powerful tool within the industrial sector, with each solution representing a vast panorama of mathematical physics, numerical methods, user interfaces and visualization techniques. So great has been its success that it is used both for traditional didactic experimental methods and model analysis as well as for solving dynamic problems. The aid of FEA has been both inevitable and progressive, as the high costs and time associated with consuming experimentation have often impeded the desire to produce efficient depth of results (Versteeg, Zienkiewicz *et al*).

This paper reports the procedure and results of an FEA study performed on a multicultivator (case study) structured under the premises: validation of the design proposal, evaluation of areas detected as "critical" and optimization of geometry to reduce weight and manufacturing costs. Likewise, the results obtained from the analysis in each of the situations and cases presented are reported and discussed.

2. Methodology

The design and development of a new product consists of extracting the information by following a methodology, the architecture of the product in question and its procedural details in order to understand it. It is important to mention the methodology needed to be able to propose the solution to a need; that is, to formulate or propose a problem requires a previous analysis of the knowledge about its nature and, therefore, to have considered the important or relevant facts and concepts according to which it is possible to define in a synthetic way the problem in question.

It is also worth mentioning that it is often necessary, for the benefit of the progress of an investigation, to follow methodologies that have already been defined or to follow some variant based on those already mentioned. Fig. 1 presents the methodology used to develop the design of the multicultivator under study in this work, which is an integration of the traditional models developed by Pugh, Ullman, Ulrich et al. and Pahl et al.

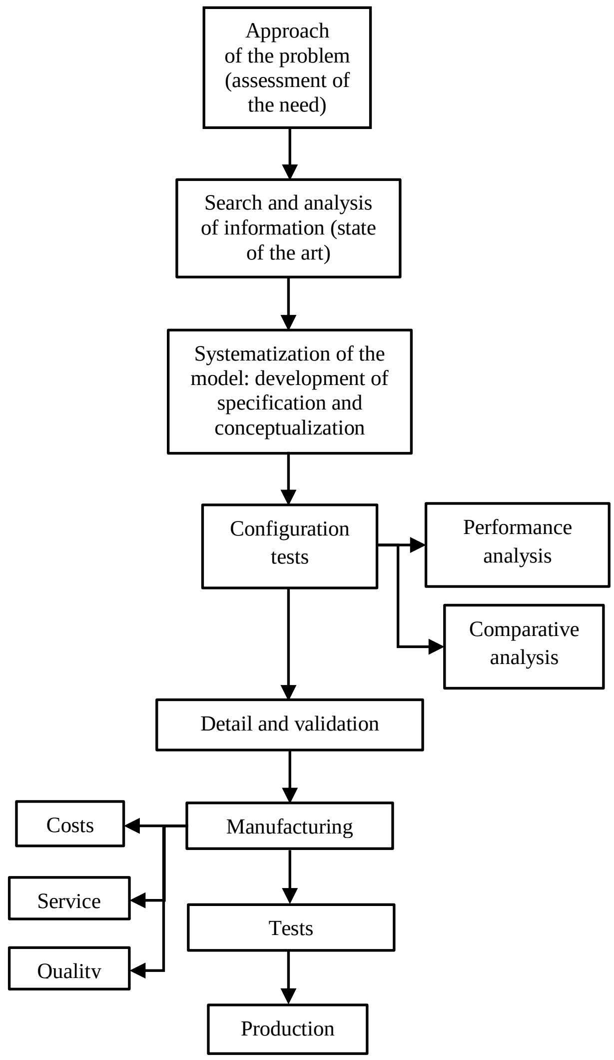

Figure 1 Design Methodology
Source: Own Elaboration

To define the design of the multicultivator, the following approaches were considered: architecture validation, production quality improvement and cost reduction; based on the aforementioned approaches, several configurations were proposed and reviewed to solve the problem under study. Several configurations were conceptualized taking into account the defined approaches and finally the final architecture of the multicultivator was generated. The final proposed geometry is shown in Fig. 2.

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3. Study approach

3.1 Objective of the analysis

To analyze the main structure of the multicultivator to ensure that it can withstand the normal workloads in an acceptable manner and to locate, in case of occurrence, critical areas of stress concentration and to argue for the possible optimization of these areas.

Figure 2 Case study
Source: Own Elaboration

3.2 Application of boundary conditions

In order to define the most adequate mesh size for the finite element study, several sizes were verified and due to the existing dimensional relationships between the analysis components, a density of 0.375in was finally selected, considering this size the most optimal for such analysis (see Figs. 3 and 4).

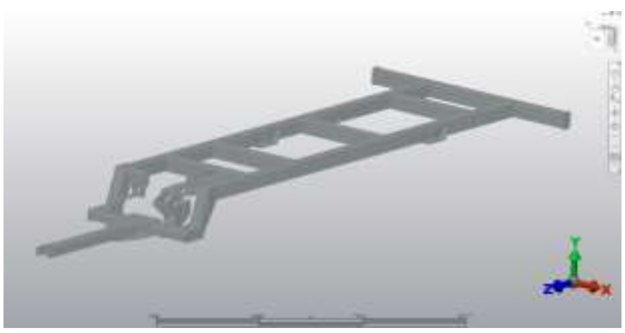

Figure 3 Meshing of the multicultivator chassis.
Source: Own Elaboration

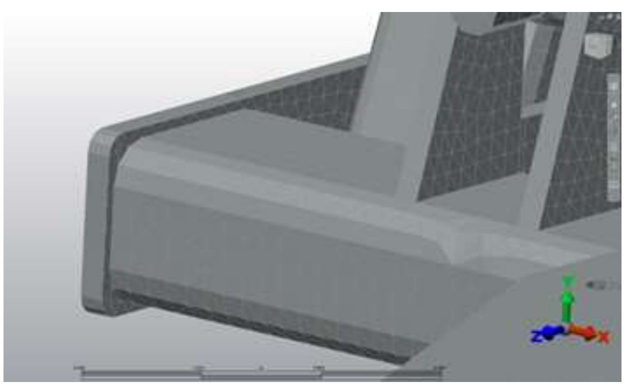

Figure 4 Detail of the multicultivator chassis meshing
Source: Own Elaboration

The loading conditions proposed for the finite element analysis of the multicultivator chassis were defined in several groups to study different situations:

a. Simulation of the pull by the tractor and restriction of the degrees of freedom on one side of the chassis.
b. Simulation of pulling by the tractor and restriction of the degrees of freedom on both sides of the chassis.
c. Simulation of the tractor pulling and application of a transverse load on one side of the chassis.
d. Simulation of pulling by the tractor and restriction of the degrees of freedom on one of the multicultivator drawbars as a sudden stop due to a foreign object on the ground.
e. Simulation of pulling by the tractor and restriction of the degrees of freedom in the multicultivator tiller as part of the resistance of the ground due to normal work.

4. Study situations

4.1 Case 1: analysis carried out on the multicultivator chassis simulating the pull on the tractor hitch part and restriction of degrees of freedom on one side.

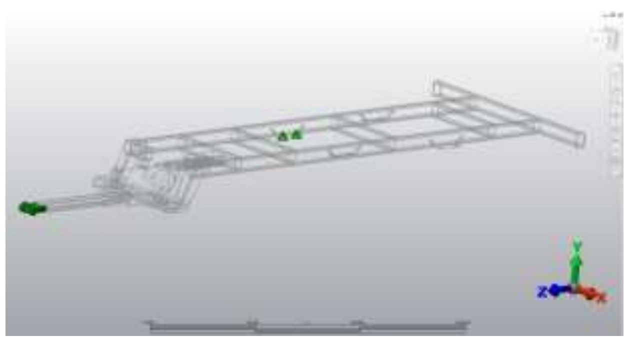

Figure 5 Load groups applied
Source: Own Elaboration

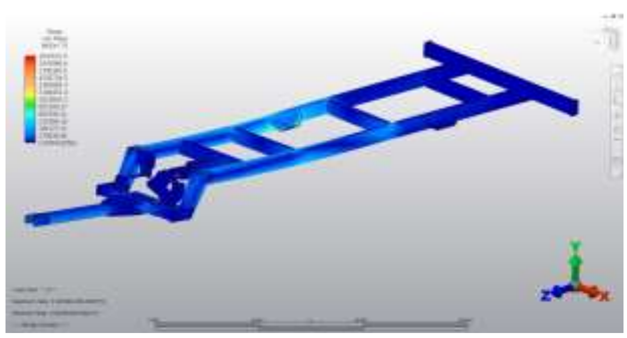

Figure 6 Multicultivator chassis stresses for case 1
Source: Own Elaboration

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4.1 Analysis of results: Case 1

In this study, the normal working load (pull) exerted by the tractor on the multi-cropper chassis was applied to the model and the degrees of freedom were restricted in one of the main longitudinal members, as shown in Fig. 6.

The stress analysis shows that the stress magnitudes are below the elastic limit of the material. Therefore, the chassis structure will not present permanent deformations under the loading conditions applied during normal working process.

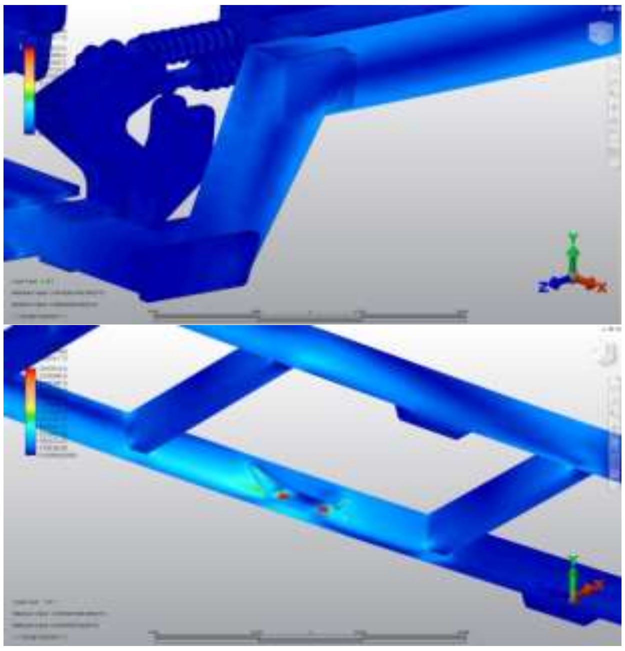

Figure 7 Detail of stresses of the Multicultivator chassis for case 1
Source: Own Elaboration

4.2 Case 2

Analysis performed on the multicultivator chassis simulating the pull on the tractor hitching part and restriction of degrees of freedom on both sides.

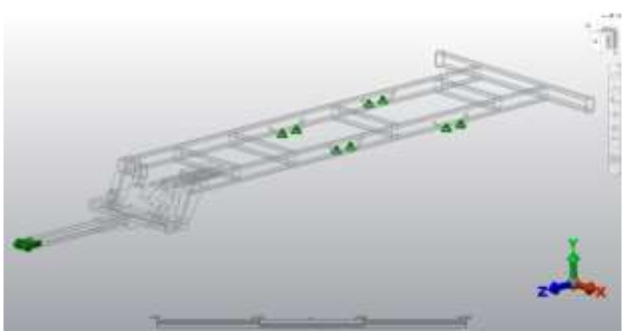

Figure 8 Load groups applied
Source: Own Elaboration

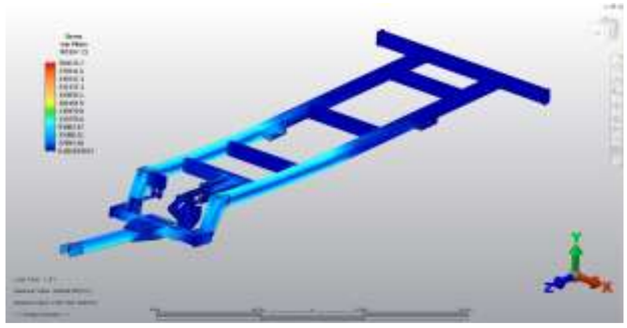

Figure 9 Multicultivator chassis stresses for case 2
Source: Own Elaboration

Analysis of results: Case 2

In this study, the normal working load (pull) exerted by the tractor on the multicultivator chassis was applied to the model and the degrees of freedom in both main longitudinal members were restricted, as shown in Fig. 9. The stress analysis shows that the stress magnitudes are below the elastic limit of the material.

It is worth mentioning that, although the stress magnitudes increased with respect to the results in case 1, they still remain within the normal deformation ranges of the material. Therefore, the chassis structure will not present permanent deformations under the loading conditions applied during the normal working process.

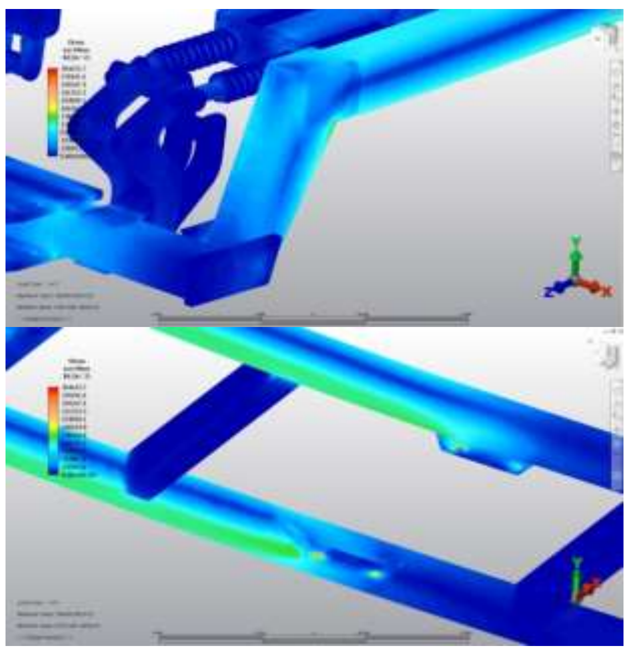

Figure 10 Detail of stresses of the multicultivator chassis for case 2.
Source: Own Elaboration

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4.3 Case 3

Analysis performed on the multicultivator chassis simulating the pull on the tractor hitching part and restriction of degrees of freedom on one side.

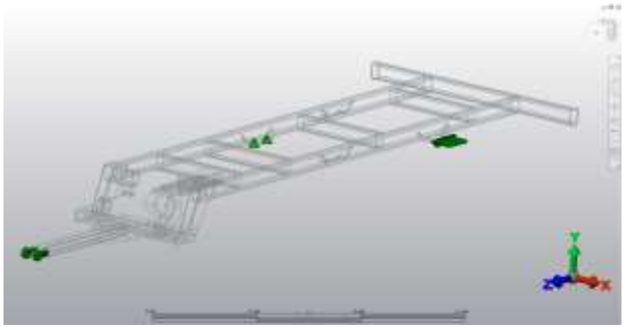


Figure 11 Load groups applied
Source: Own Elaboration

Analysis of results: Case 3

In this study, the normal working load (pull) exerted by the tractor on the chassis of the multicultivator was applied to the model and a transverse load of 50000Lbf was applied to one of the main longitudinal members, as shown in Fig. 12. The stress analysis shows that the stress magnitudes are below the elastic limit of the material.

It is worth mentioning that, although the stress magnitudes increased with respect to the results in case 1, they still remain within the normal deformation ranges of the material. Therefore, the chassis structure will not present permanent deformations under the loading conditions applied during the normal working process.

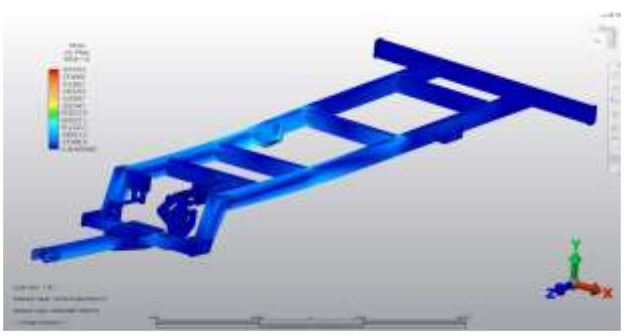


Figure 12 Multicultivator chassis stresses for case 3
Source: Own Elaboration

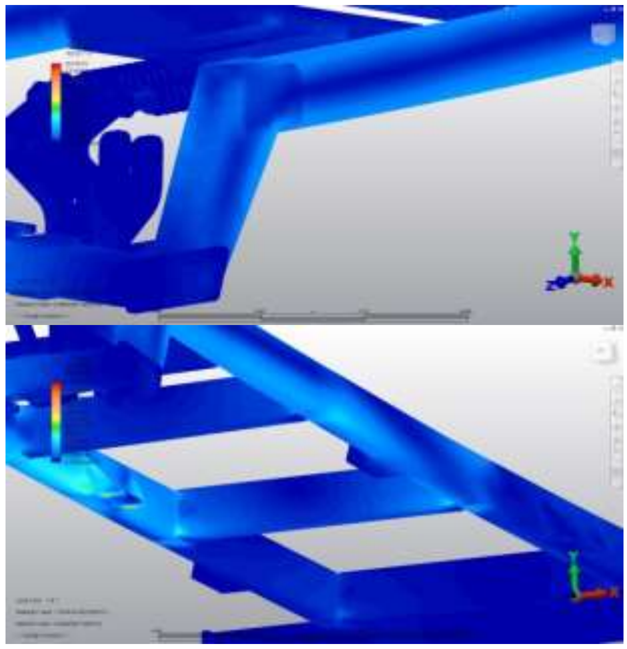


Figure 13 Detail of stresses of the multicultivator chassis for case 3
Source: Own Elaboration

4.4 Case 4

Analysis performed on the multicultivator chassis simulating the pull on the tractor hitching part and restriction of degrees of freedom in one of the multicultivator's rudders as a sudden stop due to a foreign object on the ground.

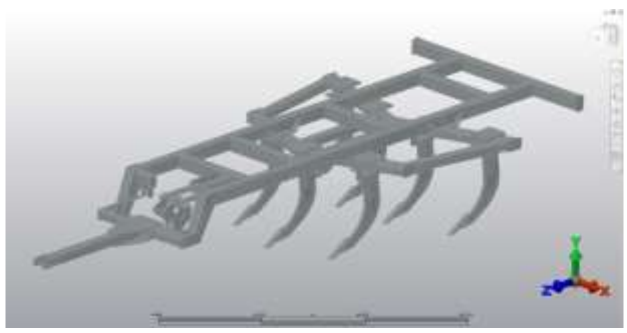


Figure 14 Chassis meshing and multicultivator system
Source: Own Elaboration

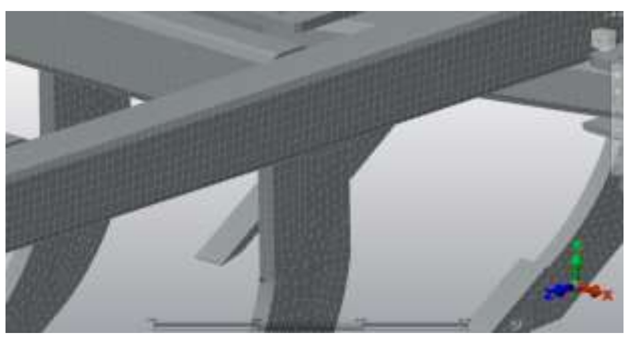


Figure 15 Detail of chassis meshing and multicultivator system
Source: Own Elaboration

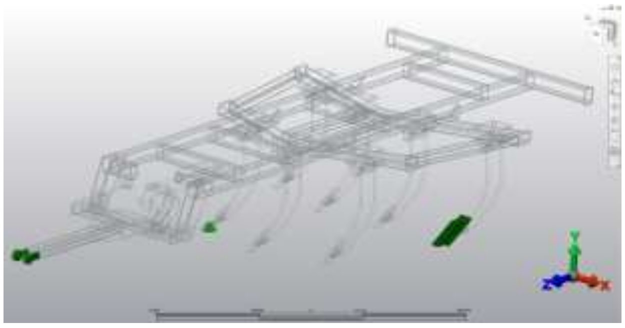


Figure 16 Load groups applied
Source: Own Elaboration

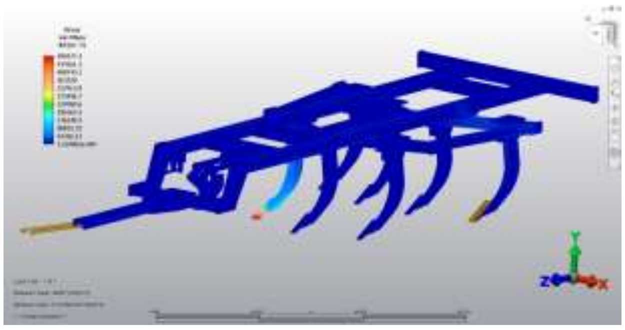
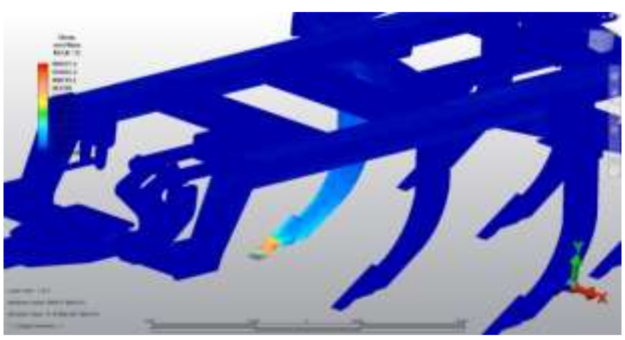


Figure 17 Multicultivator chassis stresses for case 4
Source: Own Elaboration

Analysis of results: Case 4

In this study, the normal working load (pull) exerted by the tractor on the multicultivator chassis was applied to the model and a pivot was placed to restrict the degrees of freedom in this area. A load of 7510.70Lbf was applied to one of the tiller to simulate a sudden stop due to the presence of a foreign object on the working ground, as shown in Fig. 17.

The stress analysis shows that the stress magnitudes are below the yield strength of the material. Therefore, the chassis structure will not present permanent deformations under the loading conditions applied during normal working process.



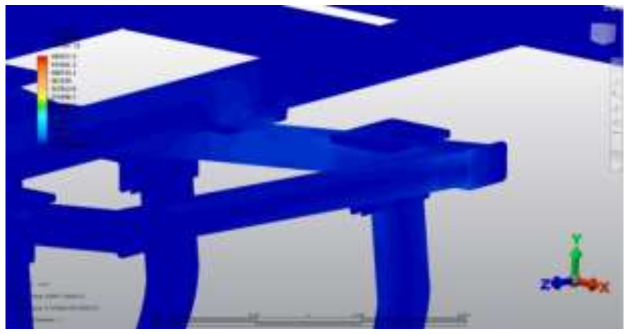


Figure 18 Stress detail of the multicultivator chassis for case 4
Source: Own Elaboration

4.5 Case 5

Analysis performed on the multicultivator chassis simulating the pull on the tractor hitching part and restriction of degrees of freedom on the multicultivator tiller as part of the ground resistance due to normal work.

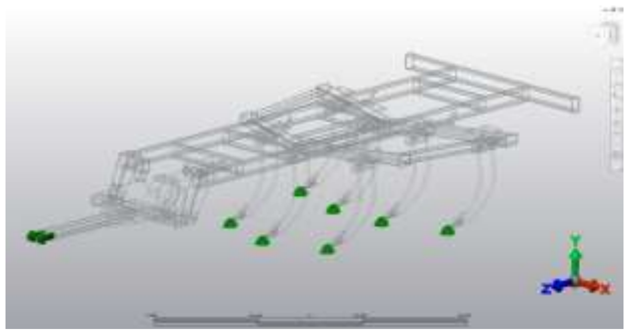


Figure 19 Load groups applied
Source: Own Elaboration

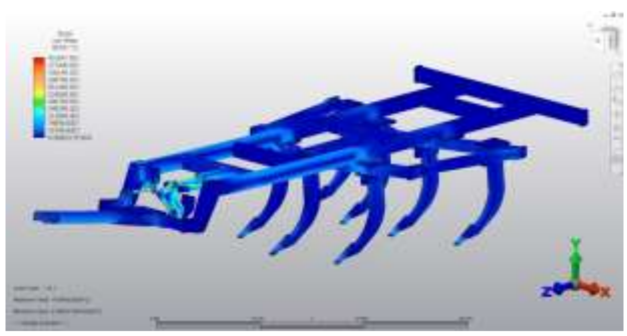
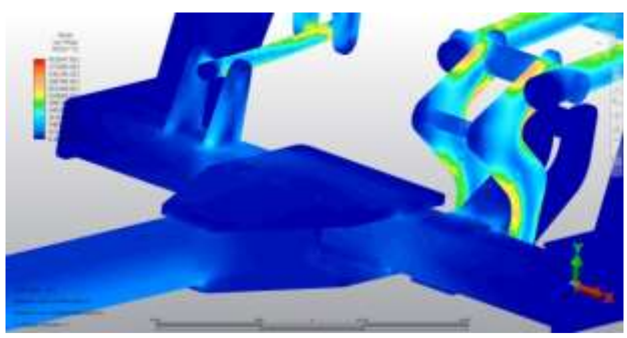


Figure 20 Multicultivator chassis stresses for case 5
Source: Own Elaboration



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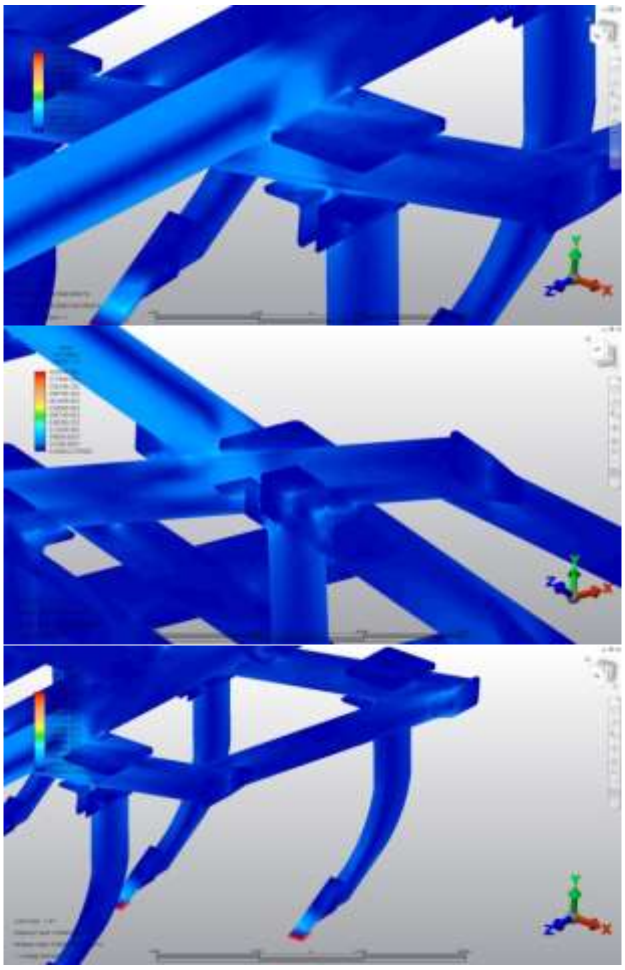

Figure 21 Stress detail of the multicultivator chassis for case 5
Source: Own Elaboration

Analysis of results: Case 5

In this study, the normal work load (pull) exerted by the tractor on the multicultivator chassis was applied to the model and the degrees of freedom in the multicultivator rudders were restricted to simulate the resistance of the soil due to normal and sudden work of the multicultivator, as shown in Fig. 19. As can be seen in Fig. 20, the damping zone of the chassis presents the highest stress magnitudes.

The stress analysis shows that the stress magnitudes are below the yield strength of the material. Therefore, the chassis structure will not present permanent deformations under the loading conditions applied during normal working process.

5. Results (global analysis)

The stress study carried out on the chassis of the multicultivator shows that each and every one of the elements that make up the chassis present stress magnitudes below the permissible elastic limit of the material. In the damping zone of the chassis is where the highest stress magnitudes are found, showing stress concentration at some points, this is due to the geometry itself and the work under which the elements of this part work. Even so, these magnitudes are within the normal deformation ranges, so they can be disregarded for the moment to continue with the analysis.

The chassis longitudinal members were considered as critical elements to apply the loads because they have the largest dimensions and are the main parts of the chassis. Likewise, it was decided to analyze the chassis by integrating the multicultivator to ensure even more the resistance that the implement will have in normal work. The analysis also shows that the chassis structure of the multicultivator is sufficiently rigid to support and absorb the work loads to which it will be subjected.

6. Acknowledgements

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7. Conclusions

The use, development and implementation of methodologies for the design or redesign of products based on new technologies increases the probabilities of market alignment and the increase of knowledge and technology transfer to the industrial sector.

Advances in computational and technology analysis allow engineers, designers and researchers to have effective diagnostic and simulation tools that facilitate, at a given moment, the design, redesign or optimization of a mechanical system.

In this article, the results obtained from the FEA study performed on a multicultivator were presented in order to verify the design and to support, if necessary, the optimization of geometry to avoid stress system concentration.

On the other hand, with these results it was possible to make changes to the main structure of the multicultivator and, under the approach of weight and manufacturing cost reduction, it was also feasible to generate application strategies for the assembly of such implement and, in this way, facilitate the alignment to mass production.

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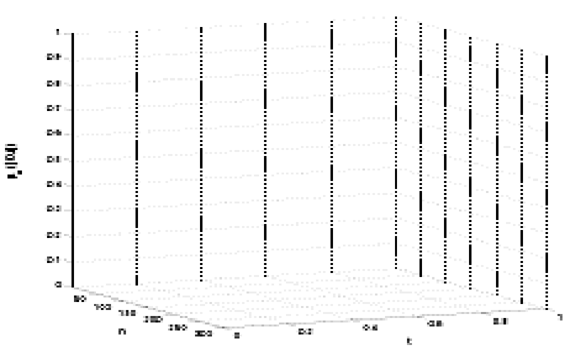

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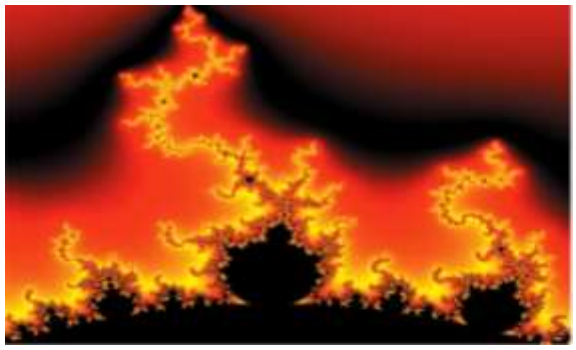

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