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In the first article we present, *Application of Strategies on NSGAII for Searching of Optimal Solutions to the Car Sequencing Problem*, by GUZMÁN-SANDOVAL, Alonso Eric, PUGA-SOBERANES, Héctor José, SORIA-ALCARAZ Jorge Alberto and CARPIO-VALADEZ, Juan Martín, with adscription in the Tecnológico Nacional de México/ Instituto Tecnológico de León and Universidad de Guanajuato, as the next article we present, *Methodology for detection of suicidal ideation in texts from the analysis of suicide notes*, by PADILLA-NAVARRO, Christian, AGUILAR-DURÓN, Rebeca, AGUILERA-GONZÁLEZ, Gabriel and YAÑEZ-VARGAS, Juan Israel, with adscription in the Universidad Politécnica de Juventino Rosas, as the next article we present, *Simulation of a point-to-point wireless communication with XBEE technology for monitoring environmental variables*, by PEREZ-GARCIA, Víctor, YAÑEZ-VARGAS, Israel, QUINTANILLA-DOMINGUEZ, Joel and AGUILERA-GONZALEZ, José, with adscription in the Universidad Politécnica de Juventino Rosas, as the next article we present, *PID Instrumented Control Elements Estimation Based on Probabilistic Methods*, by GARCIA-HERRERA, Mariel Fernanda & PEREZ-CARETA, Eduardo, with adscription in the Universidad de Guanajuato.

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Application of Strategies on NSGAII for Searching of Optimal Solutions to the Car Sequencing Problem

Aplicación de Estrategias Sobre NSGAII Para Búsqueda de Soluciones Optimas al Problema de Secuenciación de Vehículos

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Abstract

One of the main conflicts in a car production plant is to deliver the orders received daily in a timely manner, which are not uniform and involve a large amount of human and material resources. The car sequencing problem is a NP-Hard problem that consists of finding the sequence of cars that minimizes the number of constraint violations in an assembly line. The problem can be approached from a mono-objective or multi-objective point of view. The objective of this paper is to treat a case study of this problem, presented at ROADEF 2005, from the multi-objective Pareto approach, taking the NSGAII algorithm as a basis for a proposal scheme and verifying its feasibility. A systematic and general improvement of the quality of the final Pareto fronts is verified, and the results of the implementation of a strategy scheme that consists of the initialization of the population guided by local search, and specialized crossover and mutation operators are reported. These results allow us to give continuity to the generation of an optimization proposal for the vehicle sequencing problem.

Evolutionary Algorithms, Multi-Objective Optimization, Car Sequencing

Resumen

Uno de los principales conflictos en una planta de producción de automóviles es entregar en tiempo y forma los pedidos recibidos diariamente, los cuales no son uniformes e involucran una gran cantidad de recursos humanos y materiales. El problema de secuenciación de automóviles es un problema de complejidad NP-Duro que consiste en encontrar la secuencia de automóviles que minimice el número de violaciones de restricciones de una línea de ensamblaje. El problema se puede abordar desde un punto de vista monobjetivo o multiobjetivo. En este trabajo se tiene como objetivo tratar un caso de estudio de este problema, presentado en el ROADEF 2005, desde el enfoque multiobjetivo de Pareto, tomando como base para un esquema de propuestas el algoritmo NSGAII y verificar su factibilidad. Se constata una mejora sistemática y general de la calidad de los frentes de Pareto finales, y se reportan los resultados de la implementación de un esquema de estrategias que consta de la inicialización de población guiada por búsqueda local, y operadores de cruza y de mutación especializados. Estos resultados permiten dar continuidad a la generación de una propuesta de optimización al problema de secuenciación de vehículos.

Algoritmos Evolutivos, Optimización Multiobjetivo, Secuenciación de Automóviles

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Introduction

The *car sequencing problem* (CSP) was presented by (Parello & Kabat, 1986) as a constraint satisfaction problem in automotive factory workshops. Usually, it is described as the ordering of a sequence of vehicles within an assembly line, where a series of installation options must be assembled to each vehicle with the objective of minimizing the number of violations to restrictions in all assembly stations. Since 1990, numerous works have been reported the application of metaheuristics with a mono-objective tackling, using strategies based on constraint logic programming (Guerre-Chaley, Frein, & Bouffard-Varcelli, 1995), genetic algorithms (Warmick & Tsang, 1995) and taboo search (Zufferey, 2016), among others.

In 2005 a case study based on the CSP was presented at the ROADEF challenge. In this variation, the constraints of the original CSP are considered and identified as smoothing constraints, moreover adding a third variable related to color changes. Thus the case study tackles three optimization objectives listed right away: *color changes, high-priority overloads, and low-priority overloads*. Several proposals were presented in the challenge, highlighting *greedy strategies, local search, genetic algorithms and simulated annealing,* among others, which apply a *lexicographic multiobjetive approach*. The work of (Nguyen & Cung, 2005) resumes the best techniques applied to this case study and their results in the challenge.

Generally, performing a deep review of the state of the art, we find out that lexicographic approximations have been applied in most works related to the *CSP*. Such is the work presented by (Marquez-Sanchez & Puga-Soberanes, 2019) that exposes an exhaustive study of the *CSP*, as well as a lexicographic strategy based on differential evolution with a chromosomic repairer. Based on the results and observations of the previous work, (Velazquez & Puga-Soberanes, 2020) presents a feasibility study for the application of ~~a~~ *estimation of distribution algorithm* (EDA) with a lexicographic approach, concluding that it is a potential strategy to find feasible and optimal solutions to the problem.

However, in the state of the art exists several works that explore the problem from the multi-objective sense of *Pareto*, characterized by treating the variables of a multi-objective optimization problem simultaneously and independently. The work of (Zinflou, 2008) tackles the *CSP* with various techniques (including the lexicographic and Pareto sense), although its main contribution is the formulation and implementation of a new multiobjetive evolutive algorithm called PMS^{MO}, also applying specialized heuristics for the generation of initial population guided by greedy heuristics and recombination and mutation operators for the individuals of the population.

On the other side, the work of (Chutima & Olarnviwatchai, 2018) proposes a new case study extended from the ROADEF 2005 case, presenting additional objectives and beign tackled by a novel multi-objective EDA with a Pareto sense called COIN.

In order to provide continuity to the CSP study and the applicaton of evolutive techniques with a Pareto approach, this paper proposes a scheme of strategies to obtain optimal solutions to the problem and analyzes its effects on the performance obtained, taking as a basis the *NSGAII* algorithm (Deb, 2002) and using instances of the ROADEF 2005 challenge. We first present a formal definition and description of the characteristics of the selected performance function model for the CSP. Next, the methodology used will be described, including the strategic scheme and the details of the instances used. Finally, the results obtained from the implementation of the proposed strategies and their corresponding statistical analysis are reported to form several conclusions.

Problem description

According to (Parello & Kabat, 1986), the approach of the classic CSP indicates the search of a sequence of cars that minimizes the total number of violations to the installation constraints in the workstations of an assembly line. In the ROADEF variant, the constraints are divided in two types: soft smoothing and hard smoothing. In addition, a third variable related to the minimization of color changes is introduced.

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The established assembly constraints in each station are denoted by the ratio N/P, where N is the maximum number of cars that the station can serve without generate a volation and P is the total number of cars that always occupy the station. In synthesis, the violations (or overloads) in the station are counted only as the number of cars requiring service from the station that exceeds N.

Regarding the color changes that occur through the assembly line, these are counted taking care that there are no sub-sequences of cars of the same color that exceed the constraint of a maximum number of consecutive cars of the same color, denoted by B.

In this CSP model, a collection of cars S is the union of a set of cars D_P, that was not serviced from the previous day, with the set of cars D of the current day planned on the assembly line:

$$S = D_P \cup D = \{s_1, s_2, \dots, s_n\}, \quad (1)$$

Each car $s \in S$ has an associated vector of installation requirements taken from the set $O = HO \cup LO$, identifying high-priority restrictions by set HO, related to critical installation options in the assembly line as they require a strong load of work; and low priority constraints denoted by the set LO, related to installation options, considered as non-critical:

$$O = HO \cup LO = \{o_1, o_2, o_3, \dots o_L\} \quad (2)$$

In addition, a set of colors is established, described as:

$$C = \{c_1, c_2, \dots, c_M\}, \quad (3)$$

Of the mentioned sets, an association function links for each car $s \in S$ a color from the set C:

$$c: S \to C, \quad (4)$$

and a requirement function for a vector of options, defined as:

$$r: S \times O \to \{0,1\}$$

$$(s_i, o_j) \to r_{ij}, \quad (5)$$

$$r_{ij} = \begin{cases} 1 & if\ o_j\ is\ installed\ on\ s_i, \\ 0 & otherwise, \end{cases}$$

where s_i represents the ith car of a sequence of S into a station and o_j the j-th installation option required by the car.

Given a sequence of all the elements of S, randomly ordered, expressed as a vector $\vec{s} = [s_1, s_2, \dots, s_n]$, the cost function is defined as:

$$F(\vec{s}) = (F_1(\vec{s}), F_2(\vec{s}), F_3(\vec{s})), \quad (6)$$

where $F_1, F_2, F_3 \in \{FC, FH, FL\}$ and FC, FH and FL correspond to the cost functions of color changes, high priority constraints and low priority constraints respectively. The FC function only counts color changes of cars given in the sequence, while the FH and FL functions count constraint violations using the generic expression:

$$\sum_{i=1}^{|O|} FE_i(\vec{s}), \quad (7)$$

where $FE_i(\vec{s})$ represents the cost function applied to the i-th workstation and it can be replaced by any of the FH_i or FL_i functions for high or low priority constraints respectively.

To calculate the overloads, the sliding window mechanism proposed by (Bolat & Yano, 1992) was used, assuming that the windows W_k have a size equal to k. The size of each window depends on the ratio constraints N_i/P_i, wich is unique in the ith position of the sequence. The size of the first set of windows and the middle windows is always equal to the denominator P_i,whereas the size of the last windows is adjusted by:

$$NewP_i = P_i - 1, \quad (8)$$

$$k = N_i + 1, \quad (9)$$

where $NewP_i$ denotes only the size of the first window of the set of final windows. By assumption, in the last windows the value of P_i will exceed the total size of the vector $\vec{s}$, so this value should decrease as it progresses until it reaches a value equal to k, which is the value of the last window of the set of final windows. In this way, a slip of W_k (in a sequence of k consecutive vehicles) calculates the overloads through the expression:

$$FE_i(\vec{s}, W_k) = max\{(\sum_{i=1}^{|E|} E_i(s)\ in\ W_k) - N_i\}, \quad (10)$$

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where E represents the count of occupied cars in a station, evaluating the frtness function on the position of the car s. Since it is substraction, the value of the overloads on the ratio N_i/P_i could be $FE(S, W_k) < 0$, in which case the number of overloads in the slip automatically becomes 0.

With the given information about the model, the fitness evaluation function for each workstation is calculated with the expression:

$$FE_i(\bar{s}) = \sum_t^v FE_i(\vec{s}, W_{P_i}) + \sum_k^{NewP_i} FE_i(\bar{s}, W_{NewP_i}), \quad (11)$$

Next, v and t represent the limits of the final windows where v is constant and t is variable, such that $t \to v$. $|c'|$ corresponds to the total number of cars from the given starting position in the sequence, while $\#n$ is the number of cars in each window and c corresponds to the starting position of the first window. The size of the window is reduced after counting by the window until $t = v$. This is done with the following expressions:

$$t = |c'| - \#n, \quad (12)$$

$$v = c - NewPi \quad (13)$$

Finally, the problem consists of minimizing the cost function (6), where equations (7) and (11) are applied in the objective functions of constrains for FH, FL and taking into account the third objective function FC that only counts the color changes given in the sequence without violating a constraint B. To manage the information of the problem instances, the cars with the same requirement were grouped into classes cl_i.

Options				**Classes (cl_i)**					
O	**Prior.**	N_i	P_i	**1**	**2**	**3**	**4**	**5**	**6**
o_1	1	1	2	0	1	1	0	0	0
o_2	1	2	5	1	0	1	0	1	1
o_3	0	1	3	0	1	0	0	0	0
o_4	0	3	5	0	0	0	1	0	1
o_5	0	2	3	0	1	1	0	1	0
Cars: $\|S\| = 25$				5	5	4	4	3	4
#Colors(C)			c_1	2	1	1	2	1	1
			c_2	1	1	0	2	1	1
			c_3	1	3	2	0	0	2
			c_4	1	0	1	0	1	0

Table 1 Generic form of a CSP instance with a sequence of 25 cars *(Zinflou, Design of an Efficient Genetic Algorithm to Solve the Industrial Car Sequencing Problem, 2008).*

Table 1 illustrates the case of an instance that has a sequence of 25 cars cataloged in 6 classes, defined by the shape of the requirements vector. The priority of each option of the set O is indicated with 1 for high and 0 for low, as well as the ratio N_i/P_i for each one. In the classes section, the respective requirement vectors for each one are shown, while in the *Cars* row, the number of cars $|S|$ is indicated, followed by the number corresponding to each class cl_i. Finally, at the bottom of the table, the set of colors and the number of cars per class painted of a specific color are indicated; for example, for class 1, two cars will be painted in the color c_1, and the remaining three cars will be painted by colors c_2, c_3 and c_4 respectively.

Proposed methodology

The research methodology initially consisted of the implementation of the NSGAII algorithm as the basis for a framework of proposed strategies to tackle the CSP, previously establishing an adequate individual coding and a population initialization mechanism that helps to enhance the search process from the beginning. Subsequently, the improvement strategies were defined to guide the search of optimal solutions in the solution space, specifically the crossover and mutation operators for searching intensification and solution diversification. In the design of experiments, five different variants of NSGAII were established to systematically test each proposal, and finally we established a statistical analysis of the results of the experimentation based on the measurement of *hypervolume* (Zitzler, Laumanns, & Thiele, 2001).

a. NSGAII

Formally, the version implemented in this work was the standard generational *NSGAII* proposed by (Deb, 2002), characterized by the generation of two populations: one of the parents and the other of offsprings, denoted as P and Q respectively, which are combined in the set R, maintaining the same size in each iteration of the evolutionary process. In the algorithm a method called *non-dominated sort* is used to catalog each *non-dominated front* found. In addition, a density estimator called *Crowding Distance* (CD) is used to generate diversity in the solutions of non-dominated fronts.

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Both methods are the main criteria for the selection of individuals from the population that will enter into a evolutionary component executed by a generic genetic algorithm.

The general procedure, illustrated in Figure 1, starts with a population R that contains the populations of parents P_t and children Q_t (empty in the first generation), with t corresponding to a generation of the evolutionary process.

The population R is ordered (via Fast Non-dominated Sort function) according to the different fronts of non-dominated solutions found (denoted as F) and the density of individuals of each element is estimated (via Crowding Distance density estimation function). For a new population P_{t+1}, only the elements belonging to low-level non-dominated fronts are taken (the best in terms of minimization) and, in the case of a tie, the one with the lowest density is taken. The non-dominated solutions ordered on different fronts become the input of a genetic algorithm (GA), resulting in the population of children Q_{t+1}.

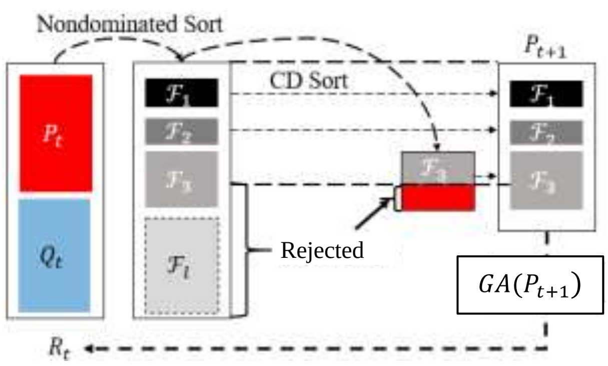

Figure 1 Scheme of the general procedure of NSGAII *(Deb, 2002)*

b. Initial population generation

In the process of generating the initial population, a random sample vector $\vec{s}_0$ of all cars is taken from the collection of cars S. This sequence is segmented into subsequences of approximately the same size, in such a way that the restriction B is not violated. In our case, the size of each subsequence is equal to the minimum value of B, beign generalized to all the instances used. After the segmentation The result is a sequence of subsequences denoted by $\hat{s}_0$.

Given the segmentation, the process perform two main steps based on guided local search (GLS) and random generation. In the first step, the fitness of the initial solution is previously calculated, denoted as F_0, and generates the first half of the initial population creating a search neighborhood with a population of empty cadidate receptors y with the same size of $\hat{s}_0$. To create those candidate receptors we seek to perturb the sequence $\hat{s}_0$. by randomly taking half of its subsequences and placing them one by one in their corresponding positions.

When a subsequence is placed there is a 10% chance of shuffling its elements, the rest of the subsequences of $\hat{s}_0$ are stored in a list denoted by L. To occupy the remaining positions of y we seek to place as many elements of the list L as possible in empty positions of y in such a way they do not generate violations in ratio constraints. The rest of the empty positions of $y$are randomly occupied with the rest of the elements of L; this process is repeated as many times to complete the neighborhood NH.

Once completed the neighborhood, the fitness of each $y \in NH$ is evaluated and compared with F_0, if its fitness is greater it is accepted into the intial population P. The process is repeated until $|P| = \lceil N/2 \rceil$. Finally, in the second step, corresponding to the second half of the initial population, the sequence $\vec{s}_0$ is taken and permuted to generate a new individual, repeating the process until $|P| = N$. The generation procedure is illustrated in detail in Figure 2.

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Input: $P \leftarrow \emptyset, N, \vec{s}$
1. $\hat{s}_0 \leftarrow$ segment($\vec{s}$)
2. Evaluate fitness of initial solution $F_0 \leftarrow F(\vec{s})$
3. $NH \leftarrow \emptyset$ Generate empty search neighborhood
4. While $P \leq N/2$
5. For $i = 1, i \leq N$
6. Generate receptor y with size $|\hat{s}_0|$
7. $L \leftarrow \emptyset$
8. For $j = 1, j < |\hat{s}_0|/2$
9. $pos_{rand} \leftarrow$ random position of $\hat{s}_0$
10. If $y[pos_{rand}] = \emptyset$, entonces
11. $y[pos_{rand}] \leftarrow \hat{s}_0[pos_{rand}]$
12. $\alpha \leftarrow$ random number between $[0, 1]$
13. If $\alpha < 0.1$, the shuffle $y[pos_{rand}]$
14. $L \leftarrow \hat{s}_0 - \hat{s}_0[pos_{rand}]$
15. For $j = 1, j < |\hat{s}_0|$
16. If $y[j] = \emptyset$
17. $l_{rand} \leftarrow$ Take random position from L
18. If $L[l_{rand}]$ in $y[j]$ does not conflict, then
19. $y[j] \leftarrow L[l_{rand}]$
20. $L \leftarrow L - L[l\_rand]$
21. Locate remaining elements from L into empty spaces of y
22. $NH \leftarrow NH \cup Y_i$
23. For each $y \in NH$
24. Si $F(y) < F_0$
25. $P \leftarrow P \cup y$
26. $i \leftarrow N/2 + 1$
27. While $i \leq N$
28. $y \leftarrow$ Shuffle $\vec{s}$
29. $P \leftarrow P \cup Y_i$
30. $i = i + 1$
31. Return P

Figure 2 Algorithm 1 Guided Local Search Based Initialization Proposal Procedure.

Figure 3 shows an example of the procedure to generate an individual for the initial population, composed of a sequence of 15 cars. The process begins by taking the initial sequence, which in the first step is segmented into five subsequences. In the second step the subsequences seq_1 and seq_3 are randomly selected and placed in their original positions into the receiver y, meanwhile the rest of subsequences are saved into the wait list L.

In the third step, of all the subsequences evaluated in each free position, the only one that was possible to place in the second position of the receiver y was the subsequence seq_4, because when it was evaluated at that position it did not cause any conflict of the ratio constraints violations.

Likewise, under the probability of 10%, this subsequence was shuffled after being placed. The wait list L keeps storing the subsequences seq_2 and seq_5 to finally begin placed in the remaining random empty positions in the fourth step.

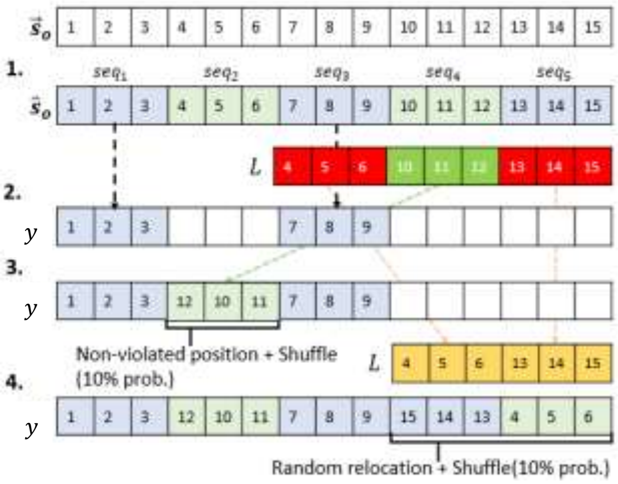

Figure 3 Schematic of the procedure of generation of individuals for the search neighborhood.

c. Recombination

The recombination operator proposal is based on the order-based crossover (*OX2*), described by (Syswerda, 1991), applying CSP-specific proportion constraint and color change satisfaction functions, which makes it an ad hoc recombination method specifically formulated for this problem.

The first step of the proposed operator, illustrated in Figure 4, consists of the selection of an individual$Parent_1$; then, sections of consecutive elements and their positions in $Parent_1$ that do not violate hard or soft constraints are located and stored with their original positions inside the descendant H, of size $|Parent_1|$, and those elements that generate conflict are stored in a wait list L.

The same evaluation process is performed on $Parent_2$, looking up for the original positions, but excluding those that are already inside or whose original positions are already occupied in H. The elements of L are inserted into H starting from the first empty position and going forward evaluating that they do not conflict at any position or else they remain in L. The remaining elements are inserted in the free positions of H starting from the first empty position found.

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The entire process is repeated starting with the indvidual $Parent_2$ for a second descendant.

Input: $Parent_1, Parent_2$
1. Create empty receptor H with size $|Parent_1|$
2. $L = \emptyset$
3. For $i \leftarrow 1, i \leq |H|$
4. If $check\_conflicts(Padre_1[i]) = False$, then
5. $H[i] \leftarrow Parent_1[i]$ (Takes original position in H)
6. Else, $L \leftarrow L \cup Parent_1[i]$ (Stored in L)
7. For $i \leftarrow 1, i \leq |H|$
8. If $Parent_2[i] \notin H \wedge H[i] = \emptyset$, then
9. Repeat steps 4-6 with $parent_2$
10. For $i \leftarrow 1, i \leq |H|$
11. If $H[i] = \emptyset$, then
12. $H[i] \leftarrow L[i]$ (Locates $L[i]$ in first empty position)
13. $L = L - L[i]$
14. Return H

Figure 4 Algorithm 2. Ad Hoc Recombination Operator Proposal Procedure for CSP.

Figure 5 ilustrates a basic example of the described procedure for two solutions consisting of 8 cars. A conflict is indicated with the value of 1 in the third and fourth rows, which corresponds to conflicts of color and installation proportions.

$Parent_1$

auto	0	3	4	7	5	1	6	2
Color	1	1	2	3	2	2	2	4
C_{cc}	0	0	1	1	0	0	0	1
C_o	0	1	0	0	1	0	0	0

$H^{[1]}$ $L_1 = \{2,3,4,5,7\}$

auto	0					1	6	
Color	1					2	2	
C_{cc}	0					0	0	
C_o	0					0	0	

$Parent_2$

auto	3	7	4	1	5	6	0	2
Color	1	3	2	2	2	2	1	4
C_{cc}	1	1	0	0	0	0	1	1
C_o	0	0	0	1	0	0	0	0

$H^{[2]}$ $L = \{2,3,7\}$

auto	0		4		5	1	6	
Color	1		2		2	2	2	
C_{cc}	0		0		0	0	0	
C_o	0		0		0	0	0	

$H^{[3]}$

auto	0	3	4	7	5	1	6	2
Color	1	1	2	3	2	2	2	3
C_{cc}	0	0	1	1	1	0	0	1
C_o	0	0	0	0	0	0	0	1

Figure 5 Scheme of the recombination procedure

For $Parent_1$, it is not observed conflicts in positions 0, 5 and 6, corresponding to the cars 0, 1 and 6. These take their original positions in $H^{[1]}$ and a wait list L is filled with the cars 2, 3, 4, 5 and 7. For $Parent_2$, it cannot be seen any indicated conflict in the positions for the cars 4, 5 and 6, but the car 6 is already present in position 7 of $H^{[1]}$. Therefore, only the cars 4 and 5 are placed in their original positions in $H^{[2]}$. Finally, the car 3 have only one color conflict, however if it is placed in position 2 of $H^{[3]}$, this conflict is canceled. The remaining elements of L are taken in order (i.e. according to their original order in $Parent_2$), starting with the car 7, which is placed in position 4, inevitably generating a color conflict, and the car 2 in the last position, also generating a conflict of color and proportion. Thus, the contrast between the amount of conflicts of the two parents with $H^{[3]}$ is appreciated, decreasing considerably in proportion violations, while in color changes the same amount of $Parent_2$ remains.

d. Mutation

There are mutation operators in the state of the art built specifically for various task scheduling problems, including the CSP, some of them are mentioned by (Chutima & Olarnviwatchai, 2018) and (Zinflou, Gagné, & Gravel, 2013). In this work, two techniques were implemented seeking the balanced intensification of the search for optimal solutions, applying it after the recombination process. Both methods, denoted by M_A and M_B, are part of an unique mutation operator denoted by M, establishing a selection threshold ($\tau = 0.5$). When comparing a random value θ with τ, it is established the mutation method for the individual H. Given this idea, the function of this operator is defined as:

$$M(H) = \begin{cases} M_A & si\ \theta < \tau, \\ M_B & otherwise, \end{cases} \quad (14)$$

where the $M(H)$ corresponds to the function of the mutation operator over H, M_A corresponds to the method "batch swap with invertion" (*BSWI*) and M_B corresponds to the method "invertion with swapping "(*IWS*). The M_A-BSWI method (see Figure 6) seeks to intensify the search for solutions that prioritizes the objective of color changes.

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This works by taking the child H, dividing it into several parts of the same size (which, as in the initialization proposal, is generalized to the minimum value of B all the instances used), resulting in a series of subsequences denoted by H'. Next, two of the subsequences are randomly chosen; if a random value α is less than a established threshold equal to 0.5, the subsequence is cut in half, generating two parts, and their positions are swapped. Otherwise, if α is greater than the threshold, the previous process is repeated, but in the second subsequence. Finally, the position of both subsequences is inverted and H' is returned to the original form of H by a "flattening" function.

Input: H, W
$H' \leftarrow$ segment H in W parts
$a \leftarrow rand(0, |H'|)$
$b \leftarrow rand(0, |H'|)$
$\alpha \leftarrow rand(0, 1)$
If $\alpha < 0.5$ then
    $swap(H'[a])$
Si no
    $swap(H'[b])$
$Invert\_Position(H'[a], H'[b])$
$H \leftarrow flatten(H')$
Return H

Figure 6 Algorithm 2. A_M-BSWI mutation method

For the second method, M_B-IWS, the objectives of constraint smoothing on workstations are prioritized. This method works by setting two exchange points a and b, chosen randomly. According to the order of the points, a cut is made to take a section of the solution that goes from point a to point b and inverts the resulting parts. Finally, two points of said section are randomly chosen, having a 50% probability of exchanging their positions, repeating the process several times. The procedure is illustrated in Figure 7.

Input: H
$a \leftarrow rand(|H|/2)$
$b \leftarrow rand(a, |H|)$
$Invert(H[a{:}b])$
For $i = 0, i < W$
    $pos_1 \leftarrow rand(H[a{:}b])$
    $pos_2 \leftarrow rand(H[a{:}b])$
    $\alpha \leftarrow rand(0,1)$
    If $\alpha < 0.5$
        $swap(H[pos_1], H[pos_2])$
Return H

Figure 7 Algorithm 3. B_M-IWS mutation method

e. Experimental design

Five NSGAII test variants, identified as NSGA_A, NSGA_B, NSGA_C, NSGA_D, and NSGA_E, were established for the experimental stage, each one of them associated with different heuristics. The primary target was to compare the performance of NSGAII variants by observing the effect over the quality of the Pareto fronts obtained. In the variants where the proposed mutation methods, BSWI and RWI, are applied simultaneously with the same probability of execution, they are identified as the heuristic $M_A \backslash M_B$, considering them a single function when applying equation (14). Something similar occurs with the random initialization (RI) and the guided local search initialization (GLSI), as they are part of the same strategy to generate two parts of the initial population.

In addition to the proposed crossover method, the heuristic OX2 (order-based crossover) was also chosen, which, according to (Syswerda, 1991), gets satisfactory results in task scheduling problems. The variant NSGA_A has random initialization (RI), OX2 crossover operator and simple swapping mutation (SM). For the variants NSGA_B, NSGA_C and NSGA_D respectively, the AM+BM mutation proposals, the initialization proposal (GLSI+RI) and the proposed crossover operator (AHX) were taken individually. Finally, in the variant NSGA_E, the three proposals were applied as a strategic framework for optimization. Table 2 shows the heuristics applied in each one of the variants.

Method	$NSGA_A$	$NSGA_B$	$NSGA_C$	$NSGA_D$	$NSGA_E$
RI	✓	✓		✓	
GLS/R			✓		✓
OX2	✓	✓	✓		
AHX				✓	✓
SM	✓		✓	✓	
MA/MB		✓			✓

Table 2. Heuristics used in the variants of NSGAII.

f. Application of the proposals and test instances

The test instances used were taken from the *Constraint Satisfaction Problem Library web repository* (*www.csplib.org*) and they are the same used in the ROADEF 2005 challenge; these are divided in three groups: *A, B* and *X.*

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Originally, each instance has a hierarchical order of objectives, which was assigned for techniques with a lexicographical approach, so it is not necessary from a Pareto approach.

According to (Nguyen & Cung, 2005), *group A* consists of 16 instances that were used for the qualifying stage of the challenge and to calibrate and refine the procedures of the proposals presented. *Group B*, consisting of 45 instances, was used in a second stage of the challenge; and *group X*, composed of 19 instances, was used to evaluate the final performance of the proposals and establish a winner. In the case of this work, a total of 15 instances were selected from all the groups: three from *group A*, eight from *group B* and four from *group X*.

Table 3 illustrates the information regarding the selected instances. In the second and third columns the number of cars for the previous day and the current day are indicated correspondingly. Next, the number of classes is indicated by $|Cl|$, then, the number of colors of the set by C and the value of the restriction B, finally the number of options of high and low priority, denoted by $|HO|$ and $|LO|$ respectively.

Instance	$\|D_p\|$	$\|D\|$	$\|Cl\|$	$\|C\|$	B	$\|HO\|$	$\|LO\|$
A							
022_3_4	15	484	18	12	145	3	6
048_39_1	18	600	158	12	10	5	12
064_38_2	30	874	25	14	15	7	2
B							
022_S22_J1	14	426	20	15	500	2	7
028_ch1_S22	20	265	91	20	15	4	3
029_S21_J6	42	731	12	12	15	4	3
035_ch2_S22	23	270	8	9	150	3	2
039_ch1_S22	31	1232	86	12	15	2	9
048_ch1_S22	310	592	181	14	10	6	19
048_ch2_S22	48	547	112	12	10	7	16
064_ch1_S22	28	826	46	14	15	11	3
X							
023_S49_J2	18	1261	79	13	40	5	7
024_S49_J2	18	1320	106	15	10	7	11
025_S49_J1	74	997	208	20	60	6	14
034_VP_S51	20	232	7	30	400	6	2

Table 3 Selected test instances and their information

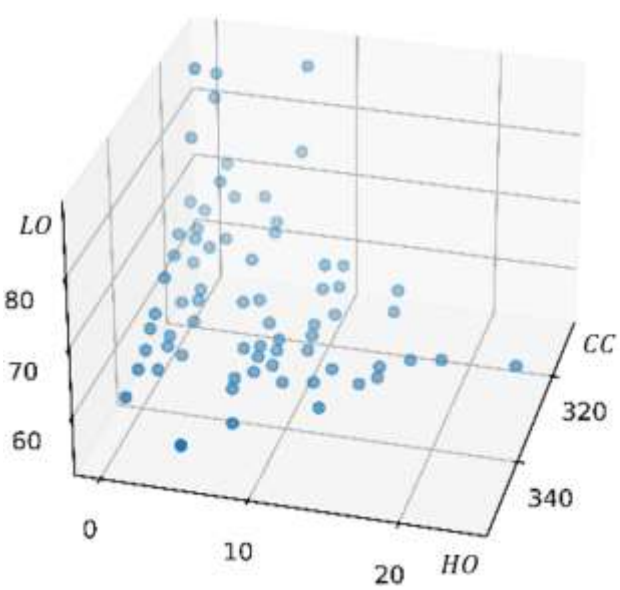
The test parameters of the experiments are illustrated in Table 4. The values for crossover and mutation rates use similar values used by works based on evolutionary computation, such as (Zinflou, Gagné, & Gravel, 2013) and (Marquez-Sanchez & Puga-Soberanes, 2019).

Parameter	Value
Populaton size	100
Archive size	100
Generations	1000
Crossover rate	0.9
Mutaton rate	0.35

Table 4 Parameters used by variants.

Archive size is used as a maximum number of non-dominated solutions for the last Pareto front found and uses the same value as *Population size* parameter. Both parameters used high values since we sought to guide a search that would yield the largest number of final solutions to compare results between the test variants of NSGAII with the different instances. The number of generations is high because we observed that in some instances (e.g 039_ch1_S22 and 023_S49_J2) the convergence with the different variants was slow.

At the end of an execution of any variant, the Pareto front of non- dominated solutions was identified as a sequence of cars with a corresponding associated list of plottable points. Graphic 1 shows the graph of the set of solutions that form the front generated by the three objective functions in the *NSGA_A* variant, using the control instance 022_3_4 of *group A*. *Graphic 2* shows the graph of the set of Pareto solutions for the *NSGA_E* variant, with the same instance.



Graphic 1 Final set of Pareto solutions returned in a typical execution of the NSGA_A variant.

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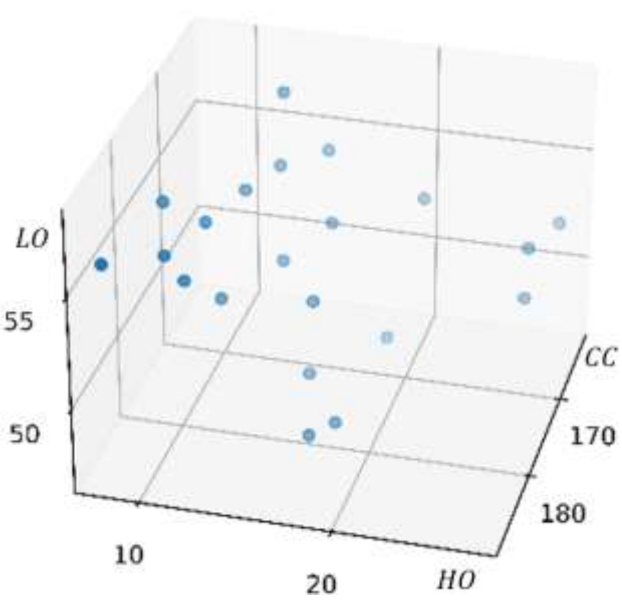


Graphic 2 Final set of Pareto solutions returned in a typical execution of the NSGA_E variant.

Results

A summary of the mean and standard deviation of the hypervolume metric from the results of 36 experiments for each group of Instances corresponding to each NSGAII, variant is shown in Tables 5-7. This metric represents a quality or performance value to the final Pareto fronts obtained in each experiment. Those instances from each group whose results are representative are highlighted in bold.

Instancia	$NSGA_A$	$NSGA_B$	$NSGA_C$	$NSGA_D$	$NSGA_E$
022_3_4	(2.59E+6 5.20E+5)	(1.45E+6 3.21E+5)	(2.13E+62.38 E+5)	2.46E+6; 2.29E+5)	(5.45E+61.53E +5)
048_39_1	(8.79E+6 1.86E+6)	(8.94E+6 1.13E+6)	(2.99E+72.50 E+6)	(3.39E+7 2.71E+6)	(3.60E+71.06E +6)
064_38_2	(1.19E+72.34E +6)	(5.09E+6 2.87E+5)	(1.04E+73.81 E+5)	(1.10E+7 4.40E+5)	(3.02E+71.13E +6)

Table 5. Summary of hypervolume metrics for selected instances in group A.

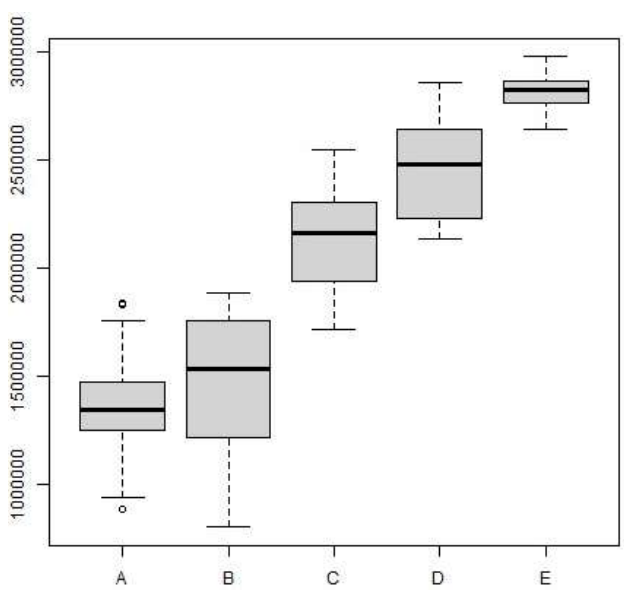
Instancia	$NSGA_A$	$NSGA_B$	$NSGA_C$	$NSGA_D$	$NSGA_E$
022_S22_J1	(1.39E+5; 1.06E+4)	(1.41E+5; 6.16E+3)	(2.17E+6; 1.22E+5)	(1.94E+6; 8.29E+4)	(2.90E+6; 8.14E+4)
028_ch1_S22	(2.90e+06; 5.95e+05)	(3.29e+06; 3.94e+05)	(3.65e+06; 3.93e+05)	(3.52e+06; 2.03e+05)	(4.55e+06; 2.82e+05)
029_S21_J6	(3.54e+06; 6.95e+05)	(3.78e+06; 6.95e+05)	(6.18e+06; 7.28e+05)	(6.54e+06; 9.38e+05)	(7.47e+06; 7.71e+05)
035_ch2_S22	(4.21e+06; 2.09e+05)	(4.31e+06; 2.11e+05)	(5.16e+06; 1.15e+05)	(4.87e+06; 4.24e+04)	(5.34e+06; 2.54e+05)
039_ch1_S22	(5.53e+06; 1.62e+06)	(5.58e+06; 2.04e+05)	(1.69e+07; 1.16e+06)	(1.64e+07; 5.99e+05)	(2.43e+07; 3.70e+06)
048_ch1_S22	(7.23e+06; 1.96e+06)	(7.33e+06; 9.49e+05)	(2.65e+07; 1.30e+06)	(2.80e+07; 4.93e+05)	(3.33e+07; 7.00e+06)
048_ch2_S22	(2.89e+07; 5.19e+06)	(2.45e+07; 2.37e+06)	(4.54e+07; 4.39e+06)	(4.72e+07; 1.74e+06)	(5.42e+07; 2.16e+06)
064_ch1_S22	(1.40e+07; 2.84e+06)	(1.29e+07; 2.03e+06)	(4.12e+07; 4.62e+06)	(4.58e+07; 3.13e+06)	(5.20e+07; 3.03e+06)

Table 6 Summary of hypervolume metrics for selected instances in group B

Instancia	SGA_A	$NSGA_B$	$NSGA_C$	$NSGA_D$	$NSGA_E$
023_S49_J2	(1.56e+074.02e+06)	(1.56e+07; 6.52e+05)	(7.39e+07; 1.40e+06)	(6.28e+07; 3.31e+06)	(7.67e+07; 2.56e+06)
024_S49_J2	(3.89E+071.19E+07)	(3.84E+07; 7.12E+06)	(1.43E+08; 1.79E+06)	(1.63E+08; 3.57E+06)	(1,96E+08; 5.19E+06)
025_S49_J1	(5.21e+079.78e+06)	(5.87e+07; 1.33e+07)	(7.35e+07; 8.55e+06)	(7.72e+07; 8.19e+06)	(9.93e+07; 5.24e+06)
034_VP_S51	(4.84e+077.39e+06)	(4.80e+07; 1.03e+07)	(1.28e+08; 1.63e+07)	(1.37e+08; 1.25e+07)	(1.58e+08; 8.55e+06)

Table 7 Summary of hypervolume metrics for selected instances in group X.

The results show that NSGA_A and NSGA_B have means close to each other with respect to the other configurations, and that NSGA_C and NSGA_D have higher means than the other variants. This indicates an improvement as the effect of the initialization and recombination proposals, respectively. In the case of the NSGA_E, which integrates the three proposals (initialization, crossover and mutation), in general, higher mean values are observed, with respect to the NSGA_C and NSGA_D, showing an improvement in the generation of Pareto fronts from the point of view of the Hypervolume metric. Graphics 3-5 give a visual perspective, showing the box plots of the representative instances 022_3_4, 35_ch2_S22 and 34_VP_S51 marked in bold in Tables 5-7.



Graphic 3 Variants box plots, corresponding to instance 022_3_4.

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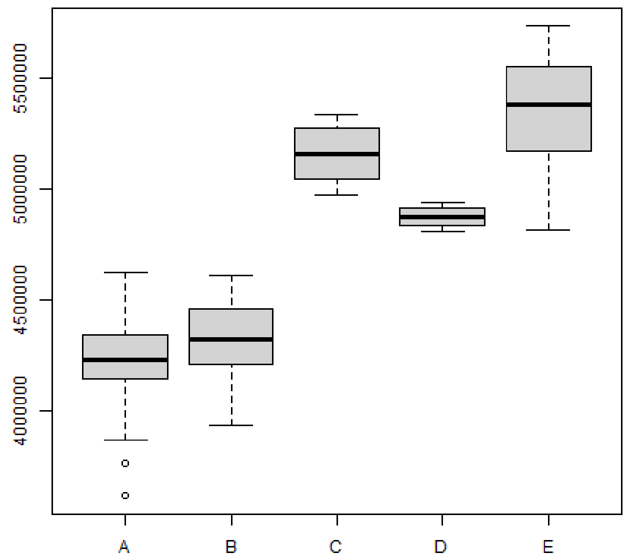
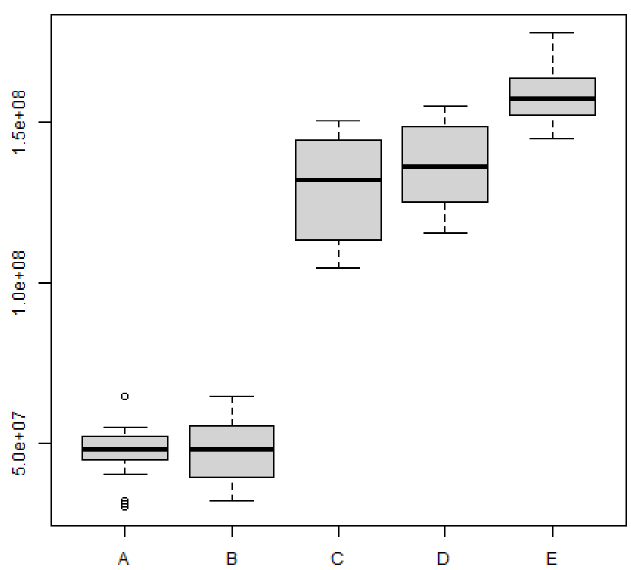


Graphic 4. Variant box plots, corresponding to instance 35_ch2_S22



Graphic 5. Variant box plots, corresponding to instance 34_VP_S51

In some instances, such as 35_ch2_S22 and 022_3_4, it is observed that the dispersion of the hypervolume values of variants NSGA_B, NSGA_C and NSGA_D is greater than the other configurations, this may be due to the fact that, individually, the proposals overexploited the search in different regions of the solution space, yielding disparate results in each experiment.

For a more rigorous analysis of the performance of each variant and its results with each of the instances, analysis of variance (ANOVA) and pairwise comparison were applied, with a significance level of 0.05, whose results are shown in Tables 8, 9.

Pairwise test yields *P* metric values between the groups {NSGA_A,NSGA_B} and {NSGA_C ,NSGA_D} that indicates no statistically significant diference, being insufficient evidence of the difference and superiority of a variant over the other. However, between the groups {NSGA_A, NSGA_C, NSGA_D} and NSGA_B, NSGA_C, NSGA_D} a significant difference is shown, suggesting that at least the group {NSGA_C, NSGA_D} is superior to the group {NSGA_A, NSGA_B}. On the other hand, the difference between the group {NSGA_A, NSGA_B, NSGA_C, NSGA_D} and the NSGA_E variant shows *P* values below the level of significance, which suggests the significant difference and superiority of NSGA_E.

In the ANOVA test, the sample population is the total of the experiments executed with all the variants. Then, the population was divided by each test variant. All the hypervolume values of each experiment for each variant were taken and their means were calculated and compared, showing that they are statistically different. In other words, a significant difference is observed between NSGA_A and NSGA_E, and also between the groups {NSGA_B, NSGA_C} and {NSGA_B, NSGA_D}, for all instances. In this context, two hypotheses are proposed: a null hypothesis that suggests no difference between the groups of configurations and means; and an alternative hypothesis suggesting significative difference between variants and means. The results of the *F* metric (less than 0.05) support the alternative hypothesis.

	Df	Sum Sq	Mean Sq	value	Pr(>F)
Algoritmo	4	2,86E+22	7,14E+21	560.7	< 2.2e-16
Instancia	373	2,47E+23	6,61E+20	51.9	< 2.2e-16
Residuals	4347	5,54E+22	1,27E+19	-	-
-	-	-	-	-	-

Table 8 ANOVA test results

Alg.	A	B	C	D
B	1	-	-	-
C	< 2e-16	< 2e-16	-	-
D	< 2e-16	< 2e-16	1	-
E	< 2e-16	< 2e-16	1.3e-13	1.9e-11

Tabla 9 Pairwise Comparison test results

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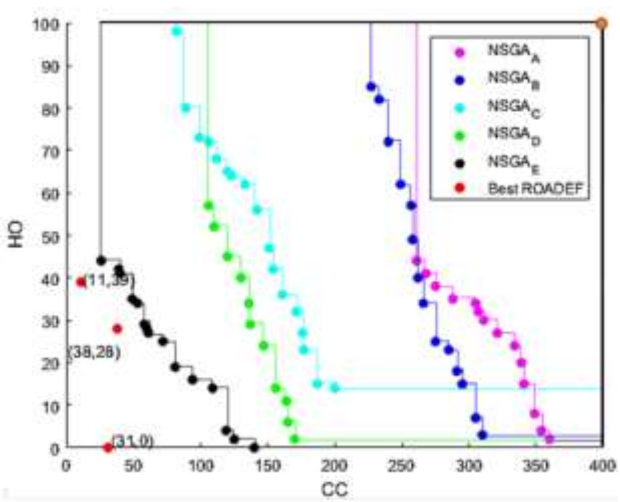
Graphic 6 shows the graph of the final Pareto fronts generated by the different test variants, taking into account the objectives of color changes (CC) and overloads in high priority options (HO) and the composition of their hypervolumes, only in the case of instance 022_3_4. The systematic improvement of the proposals is more distinguishable if we observed the size of the "areas" formed from a maximum reference point (orange point) towards all the points of each front. The larger the "area", the greater the hypervolume metric, and greater the performance of the variant.

Despite the fact that it was sought to intensify the search in an adequate and balanced way, the solutions which obtained higher ranges in HO objective (approx. [0.100]) suggest that, the mechanism used could be improved by defining more restrictions in the proposals that would give a better focus to the search, however this could have negatively affected the complexity of the algorithm and its computational performance.

On the other hand, one of the observed advantages of the Pareto approach, although the difference in the extreme solutions of the fronts of said variants is wide, the greater variety of solutions offered by the decision maker of the algorithm provides several alternatives. close to, or even better (depending on the objective to be optimized), to the final solutions of the best qualified techniques in the ROADEF 2005 and other techniques with a lexicographical approach in the state of the art (Nguyen & Cung, 2005), marked with red dots.



Graphic 6. Layout of solutions of each NSGA II variant and the best proposals of ROADEF 2005, tackling instance 022_3_4.

The opposite nature of the objectives of the problem was also observed, clearly influencing the results obtained and hindering the generation of optimal Pareto fronts. Initially, the smoothing objectives (FH, FL) are seen to benefit more in solutions composed of very small groups of cars of the same color. The opposite occurs in the objective of color changes, with large groups of cars of the same color being more beneficial, as long as constraint B is not violated.

Likewise, those N/P ratio constraints where the numerator N is close to the denominator P, generate a smaller number of violations in the workstations. These two facts were taken into account for the formulation of the proposals.

Conclusions

This work adress the car sequencing problem from a multi-objective Pareto sense. As far as is known, in the state of the art there are just a few works that tackles this problem in this way, most of the researchers use multiobjective lexicographical approximations.

Initialization, crossover and mutation strategies were presented specifically formulated for the CSP, that is distinguished by the definition of its constraints and the contradictory nature between smoothing and color constraints. The framework, constituted by the proposals, was applied over NSGAII, allowing us to establish test variants that made possible the measurement of the impact on the general improvement and the quality of the optimal solutions obtained, both for each strategy individually and as a whole. The experiments used instances of the ROADEF 2005 and the hypervolume metric to measure the quality of the results.

The statistical tests show that there is a significant difference between the algorithm used without any proposals and the same one applying the proposals; the results show that there is a systematic improvement, being the NSGA_E variant, which includes all the proposals, the one that generally presents the better performance. Our research gives viability and leaves open the process of continuity and improvement of Pareto fronts with the proposal.

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This work contributes to the research process to find optimal Pareto fronts to the multi-objective approach of the CSP. Further work is being carried out tackling the CSP according with a feasibility study of a multi-objective Pareto approach in a decomposition scheme. The study for the improvement of Pareto optimal fronts in the car sequencing problem has repercussions both in the optimization of automobile production in a timely manner and in the optimization of human and material resources.

Thanks

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Methodology for detection of suicidal ideation in texts from the analysis of suicide notes

Metodología para la detección de ideación suicida en textos a partir del análisis de notas suicidas

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Abstract

Suicide is today one of the leading causes of death in the world. People at risk of suicide commonly leave messages around them, and that often includes social media. Therefore, early detection of suicidal risk is a fundamental prevention factor. At present, the search for suicide risk based on text analysis does not consider fundamental factors such as the analysis based on suicide notes. This research proposes a new text analysis for the detection of suicidal risk based on the study of suicide notes.

Suicide notes, PLN, Suicide

Resumen

El suicidio es hoy una de las principales causas de muerte en el mundo. Las personas en riesgo suicida dejan comúnmente mensajes a su al rededor, y eso muchas veces incluye a las redes sociales. Por ello, la detección temprana de riesgo suicida es un factor fundamental de prevención. En la actualidad, la búsqueda de riesgo suicida a partir del análisis de textos no considera factores fundamentales como es el análisis a partir notas suicidas. La presente investigación propone una nueva metodología de análisis de textos para la detección de riesgo suicida tomando como base el estudio de notas suicidas.

Notas suicidas, PLN, Suicidio

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Introduction

Suicide can be defined as the act of taking one's own life, whether or not a person is in an optimal condition. It is a multifactorial and complex phenomenon, and its study must be viewed from various aspects.

According to the World Health Organisation (WHO), suicide is one of the leading causes of death in the world. In its most recent study (WHO, 2021), it was determined that one in every 100 deaths that occur in the world is due to suicide.

It is important to consider that there are different types of suicide, and not all suicides are preventable, such as altruistic suicide, in which the person seeks to use his or her own life to send a social message. But most suicides can be detected and prevented at an early stage.

Suicide involves three phases: ideation, which is when the person is just having suicidal thoughts, attempted suicide, which is when the person has already attempted to take his or her own life, and finally completed suicide, which is when the person unfortunately loses his or her life.

Both in the phases of attempted suicide and completed suicide, where the attention and risk detection should fall on the people close to the person who lost their life, it is not relevant to carry out a suicide risk detection in texts, because the risk factors are already very high and easy to locate. Therefore, our main task will be the detection of those at suicidal risk who are in the ideation phase.

Both the emotions and the feelings of a person at risk of suicide are not in the condition we expect them to be in. This is because, according to some psychologists, many of the patients at suicidal risk may be going through a phase of disengagement from reality. And, although this has not been formally proven, it is important that the analysis of texts for risk detection can emerge from the study of suicide notes, where we can understand the expressions of people with suicidal ideation.

However, current techniques for suicide risk detection tend to focus on the analysis of emotions or feelings, so it is possible that they may be making omissions in detection.

Therefore, the present research proposes a new methodology for the detection of suicidal risk in texts based on the analysis of posthumous or suicidal notes.

State of the Art

Analysis of posthumous notes

In order to carry out a text analysis based on the study of suicide or posthumous notes, one of the greatest challenges is to obtain copies of the notes. In (Leenars, 1988), an important finding was that only 12-15% of suicides leave a note, a situation that is still the case today. For this reason, over the last 30 years, experts in the field have set themselves the task of collecting as many posthumous notes as possible in order to establish criteria for their classification.

Another key element in establishing a generalised methodology was the comparison of posthumous notes between countries. In (Ashhan, 2007), (Leenaars, 1992), (Leenaars, 2001), (Leenaars, 2002), (Leenaars, 2003), (O'Connor, 2004) and (Chávez-Hernádez, 2009), comparisons were made between suicide notes from countries such as: Russia, the United States, Mexico, Turkey, Ireland and Australia and they managed to determine that they have many more coincidences than differences.

On the other hand, in (Lester, 1982), (Leenaars, 1992) and (Leenaars, 2001), it was determined that adolescents have higher scores than adults in cognitive constriction, use of indirect expressions, rejection and aggressiveness, and mechanisms related to identification-flight. They are usually preoccupied. Therefore, the detection of suicidal risk is more likely in adolescent texts as it is more evident.

Classification of posthumous notes

The classification of posthumous notes has evolved over time, mainly since 2011.

In (Chávez-Hernández, 2011) 142 suicide notes from the state of Guanajuato in Mexico were analysed. In this study, they managed to establish 11 classification categories for them.

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Subsequently, in (Cook, 2016), they established a novel methodology for the detection of suicidal risk in texts. Their percentages were established between 61% and 85% correct and it worked for Spanish in Spain. However, they used suicide detection scales for this and not suicide notes.

Meanwhile, in (Ceballos-Espinoza, 2016), 203 notes from 96 suicides in Chile were analysed. They found 24 significant differences depending on: age, marital status and gender.

Finally, in (Ceballos-Espinoza, 2019) they analysed 203 suicide notes in Chile collected between 2010 and 2013. They found that it was possible to classify them into four main aspects.

Proposed Methodology

To begin to describe the methodology, it is important to mention that it is based both on the study carried out in (Ceballos-Espinoza, 2019), and in general in the context of the state of the art study.

First, it is important to understand how effective mobilisation occurs prior to the act of suicide. The person, as previously mentioned, may go through different stages in the phenomenon of suicide. During the phase of suicidal ideation, it is more likely to find texts attached to both positive and negative affect. If the process progresses, the person may reach the depressive phase.

Finally, if the person is close to the suicidal act, their texts will reflect that they are in a state of collapse, in a state of despair. While in the positive and negative affects the person goes through emotions such as intersubjectivity and helplessness, during the depressive phase and the despair phase the person is in an evasive moment.

Such a process of effective mobilisation prior to the suicidal act can be seen in Figure 1.

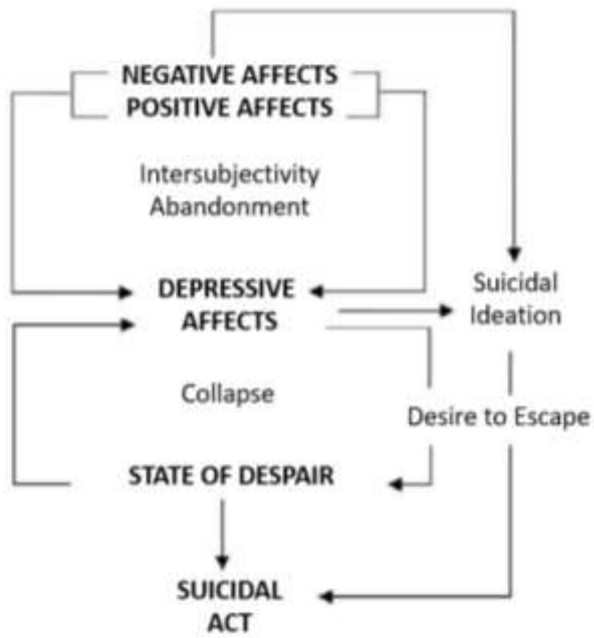

Figure 1 Effective mobilisation prior to the suicidal act
Source: (Ceballos-Espinoza, 2019)

Once this process is understood, we can then establish four main criteria for the classification of texts in the detection of suicidal risk: negative affect, positive affect, depressive affect and state of despair.

Positive affect

During the phase of positive affect it will be possible to identify mostly farewell texts, always in a positive and thankful sense. This phase can be confusing to identify, as it could be identified as an absence of risk. In Notes 1, 2 and 3, it is possible to read three examples of Positive Affect texts.

Note 1:

"Thank you for always supporting me. Thank you for forgiving me for all my mistakes. Thank you for loving me so much, because I feel and felt loved always."

Note 2:

"Chinita. I couldn't take it anymore, believe me I'm leaving loving you just as I always have with the dream of having wanted to form a home together, I love you and I will always love you and wherever I am I will take care of you."

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Note 3:

"Now I am going to be free I will no longer bother you, but I wish the best for you, in spite of everything, I loved you very much."

Negative affect

Contrary to the negative affect phase, at this stage it is possible to identify farewell texts, but mostly in the sense of anger and annoyance. This phase is much easier to identify, as despair starts to become intrinsically present. In notes 3 and 4 it is possible to see two examples of texts with negative affect.

Note 4:

"I thank you for all the love, containment and affection you showed me, but without the love of children a man is nothing. I am tired, bored, I can't make sense of anything that has happened. I have nothing to fight for anymore."

Note 5:

"I want to apologise to everyone for my cowardice and for doing what I did, but try as I might I couldn't get over it. And this new love failure has plunged me into great sorrow, knowing that I will never be able to be happy with a partner."

Depressive affects

This type of text is easy to identify, compared to the two previous phases. In them, despair is already latent, and many times they can be either positive or negative. In notes 5 and 6 it is possible to see two examples of texts in a state of despair.

Note 6:

"I thank you for all the love, containment and affection you showed me, but without the love of children a man is nothing. I'm tired, bored, I can't make sense of anything that has happened. I don't have anything to fight for anymore."

Note 7:

"I want to apologise to everyone for my cowardice and for doing what I did, but try as I might I couldn't get over it. And this new love failure has plunged me into great sorrow, knowing that I will never be able to be happy with a partner."

State of despair

In these texts, despair is already the central context. The person usually shows regret at the bottom of them. In notes 7, 8 and 9 it is possible to see three examples of texts in a state of despair.

Note 8:

"...if I have come to this, it is because I see no way out anywhere."

Note 9:

"...when my wife took up with someone else. That ended up breaking me down."

Note 10:

"Forgive me for the stupidity I am about to commit, but I can't go on with this pain and sorrow any longer, which I have been carrying inside me since my separation [...]; I can't go on with my life like this."

Conclusions

Following the analysis of the state of the art, it was possible to identify the best criteria for classifying texts for the detection of suicidal risk. It was established that the best methodology is the one proposed in (Ceballos-Espinoza, 2019), which focuses mainly on four categories: positive affect, negative affect, depressive affect and state of despair.

Future work will seek to implement this methodology in the analysis of social networks of real case studies, as well as to compare this methodology with other existing ones that do not focus on the analysis of posthumous notes.

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Simulation of a point-to-point wireless communication with XBEE technology for monitoring environmental variables

Simulación de una comunicación inalámbrica punto a punto con tecnología XBEE para el monitoreo de variables ambientales

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Abstract

This article describes the simulation of a unidirectional point-to-point radio frequency (RF) Wireless communication between two electronic circuits with XBEE technology, using the electronic design software PROTEUS V8.8. In the same worksheet in the ISIS graphical interface, the two electronic circuits were implemented, one was called the *transmitter circuit* and the other the *receiver circuit*. A Microchip® PIC16F877A microcontroller and an XBEE module are the main devices of each of the electronic circuits, to establish wireless communication by RF. The PIC microcontroller of the *transmitter circuit* was used as a DAQ data acquisition device, to measure the temperature of two analog sensors, the LM35 and the TMP36, and three digital sensors DS1621. The temperature data was sent from the *transmitter circuit* to the *receiver circuit* in character strings, using asynchronous serial communication. A programming algorithm was implemented for the PIC microcontroller of the *receiver circuit*, to receive and identify the temperature data. The development of this simulation is the basis to implement a wireless sensor network (WSN) with XBEE technology in the future.

XBEE, Acquisition, Asynchronous

Resumen

En este artículo se describe la simulación de una comunicación inalámbrica por radio frecuencia (RF) punto a punto unidireccional, entre dos circuitos electrónicos con tecnología XBEE, utilizando el software de diseño electrónico PROTEUS V8.8. En una misma hoja de trabajo en la interfaz gráfica de ISIS, se implementaron los dos circuitos electrónicos, a uno se le llamo *circuito transmisor* y al otro *circuito receptor*. Un microcontrolador PIC16F877A de Microchip® y un módulo XBEE, son los dispositivos principales de cada uno de los circuitos electrónicos, para establecer la comunicación inalámbrica por RF. El microcontrolador PIC del *circuito transmisor* se utilizó como dispositivo de adquisición de datos DAQ, para medir la temperatura de dos sensores analógicos, el LM35 y el TMP36, y tres sensores digitales DS1621. Los datos de temperatura fueron enviados del *circuito transmisor* hacia el *circuito receptor* en cadenas de caracteres, usando la comunicación serial asíncrona. Se implementó un algoritmo de programación para el microcontrolador PIC del *circuito receptor*, para recibir e identificar los datos de temperatura. El desarrollo de esta simulación es la base para implementar a futuro, una red de sensores inalámbricos (WSN) con tecnología XBEE.

XBEE, Adquisición, Asíncrono

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Introduction

A greenhouse is a closed enclosure that allows an optimal climate to be generated, to cultivate and protect crops from climatic variations. The development of crops, in their different growth phases, is conditioned by four climatic factors: temperature, relative humidity, lighting and carbon dioxide (CO_2) (Villalobos et al., 2017). There is a wide variety of crops grown under glass, and in most of them the objective is to increase size and weight. To reach this goal, each crop needs to fulfil its life process with the four climatic factors at the most favourable values. The life process of a crop is characterised by the functions of photosynthesis, respiration, growth and transpiration (absorption of water and nutrients) (García-García & Martínez-Tornero, 2016).

Plants must transpire water to transport nutrients and regulate their growth. A low relative humidity level decreases plant growth because the plant stops transpiring by closing its stomata (INTAGRI, n.d.). This is an example of the relationship between the relative humidity factor and the transpiration function of plants in greenhouse crops. Table 1 shows an example of the effect of temperature and CO_2 on photosynthesis function.

Effect of photosynthesis	Temperature level (°C)	CO_2 level (ppm)
Photosynthesis stop	Under 5	Under 300 or 400
Optimum level	From 20 to 25	From 700 to 900
Photosynthesis stop	Over 45	Over 1000 to 1100

Table 1 Effect of ambient temperature and CO_2 on photosynthesis in greenhouse crops
Source: Own elaboration, based on information from (García-García & Martínez-Tornero, 2016)

Continuous monitoring of climatic factors within a greenhouse with sensors, real-time information, and the computer capacity to store data, are the characteristics used to obtain quality information, make an objective diagnosis, and make an accurate decision in the agronomic management of the crop (AGTECH AMERICA, 2020). The monitoring of the four climatic factors within a greenhouse is important, as it provides information to make an accurate decision in the application of agrochemicals.

Figure 1 shows the stages in the process of making an accurate decision and anticipating the appearance of problems in the vegetative development of the crop.

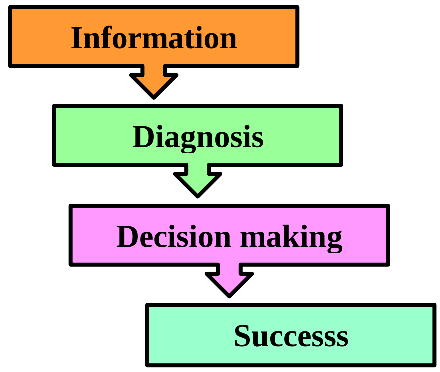

Figure 1 Stages in the process of making a good decision, and anticipating problems in the vegetative development of the crop
Source: Own Elaboration, adapted from (AGTECH AMERICA, 2020)

Wireless technology is a proposal to be implemented in the monitoring of climate variables within a greenhouse, because it provides flexibility in the installation of sensors, robustness in the network, and reduces the cost and complexity of its maintenance (Cama-Pinto et al., 2014). The XBEE radio frequency (RF) module is a small radio device that uses the IEEE 802.15.4 network protocol to create point-to-point and point-to-multipoint communication networks. These modules communicate wirelessly, and can send data from a sensor (DIGI, 2022).

Simulating an electronic circuit consists of emulating it as if it were real, and thus having a middle ground between theoretical concepts and reality. The advantages of simulating an electronic circuit are: reducing the design time without assembling it in a physical system, making the necessary modifications in less time, and anticipating problems in the behaviour of the system and unforeseen results (INDIELEC, 2021). Before physically implementing the communication between wireless devices, in order to test their behaviour between them, it is recommended to use simulation in a software simulator.

PROTEUS is a software simulator that allows designing, testing, and debugging electronic circuits before implementing a physical prototype.

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This software has a working interface called ISIS, which allows writing and applying firmware to a microcontroller, and has the ability to provide the necessary graphics for the animation of electrical and electronic circuits (Labcenter, 2022). The PROTEUS software has a library to simulate the XBEE module via serial communication. This module has two terminals enabled, the transmission (TX) and reception (RX), which allow communication quite easily with Microchip® microcontrollers, Arduino® modules, among other microcontrollers (Morán-Inga, 2019).

Serial Ports Emulator (VSPE) is a virtual port emulator software that can be used in PROTEUS to simulate wireless communication between different devices (Morán-Inga, 2019). VSPE was designed to help software engineers and developers create, debug and test applications that use serial ports. This software is capable of creating multiple virtual devices to transmit and receive data (Eterlogic, 2022).

This paper describes the simulation of a unidirectional point-to-point RF wireless communication between two electronic circuits with XBEE technology, using PROTEUS V8.8 electronic design software. In the same worksheet in the ISIS graphical interface, the two electronic circuits were implemented, one being called the transmitter circuit and the other the receiver circuit. A PIC16F877A microcontroller from Microchip® and an XBEE module are the main devices in each of the electronic circuits to establish wireless RF communication.

The article is organised as follows: in the methodology, four stages are described; in stage 1, the temperature measurement of two analogue sensors was performed with the PIC microcontroller of the transmitter circuit; in stage 2, in a new ISIS GUI worksheet, the temperature measurement of three digital sensors was simulated with the PIC microcontroller of the transmitter circuit; in stage 3, the temperature measurement of the analogue and digital sensors was performed together with the PIC microcontroller of the transmitter circuit; in stage 3, the temperature measurement of the analogue and digital sensors was performed together with the PIC microcontroller of the transmitter circuit.

In stage 4, a unidirectional point-to-point wired communication between the transmitter circuit and the receiver circuit was executed, carrying out in this process the necessary debugging to the program codes of the PIC16F877A microcontrollers, to send, convert, receive, and display the data of the analogue and digital temperature sensors. The tests and results section describes the implementation of stage 5, which consisted of using the XBEE RF modules, and verifying the unidirectional point-to-point communication between the *transmitter circuit* and the *receiver circuit*. Finally, the last section presents the conclusions and future work, mentioning what needs to be improved and implemented in the future.

Methodology

The ISIS graphical environment of the PROTEUS V8.8 electronic design automation software was used to simulate unidirectional point-to-point wireless communication with XBEE technology, using the UART module of the two Microchip® PIC16F877A microcontrollers. According to Castaño-Giraldo (2022), asynchronous serial communication or UART is one of the simplest communications used by PIC microcontrollers, and only uses three terminals: one to transmit TX data, another to receive RX data and the common GND line.

The simulation was carried out in stages, with the aim of quickly identifying and correcting syntax and semantic errors in the structure of the C language program codes of the two microcontrollers. Simulating in stages in PROTEUS helped to find connection errors between components as they were added to the ISIS graphical environment. If, when running the simulation, the electronic circuit did not behave as expected, a direct approach was given to correct the connection errors to the newly added components.

Stage 1: Temperature measurement with analogue sensors

We started by simulating the temperature measurement of two analogue sensors with linear output, the LM35 and the TMP36, using the PIC16F877A microcontroller as the data acquisition device (DAQ).

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Figure 2 shows the connection of the analogue sensors to the PIC microcontroller, and a temperature value of the TMP36 sensor displayed on the LCD (Liquid Crystal Display).

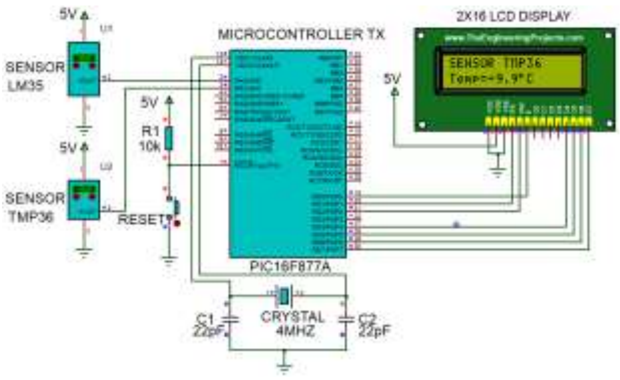

Figure 2 Temperature measurement using LM35 and TMP36 analogue sensors and a PIC16F877A microcontroller
Source: Own Elaboration, electronic diagram obtained with PROTEUS ISIS environment

The connections of the input and output devices to the PIC microcontroller were as follows: the LM35 sensor was connected to the RA0/AN0 analogue terminal, the TMP36 sensor was connected to the RA1/AN1 analogue terminal, and to display the temperature values of the analogue sensors, an LCD display was connected to the C port terminals.

C programming language was used to write the program code for the PIC microcontroller. The program code was edited and compiled in the CCS Compiler, according to Garcia-Breijo (2008) this compiler was developed specifically for Microchip microcontrollers.

Stage 2: Temperature measurement with digital sensors

In a new graphical work environment in ISIS, the acquisition of temperature data from three DS1621 digital sensors with I2C (Inter-Integrated Circuit) serial communication protocol was carried out, using a PIC16F877A microcontroller as DAQ device. Figure 3 shows the connection of the three DS1621 digital sensors to the PIC16F877A microcontroller, and a temperature value displayed on the LCD screen.

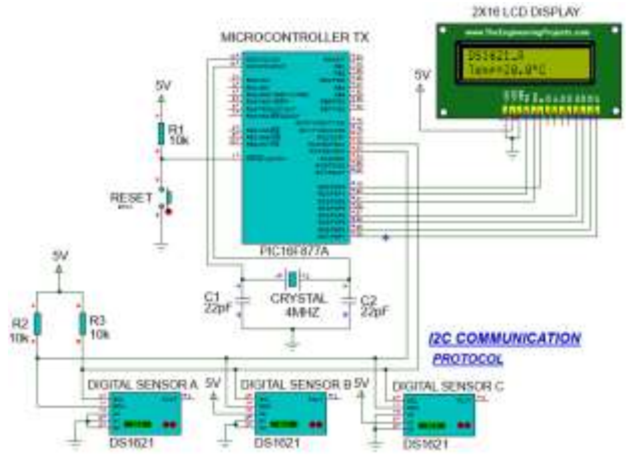

Figure 3 Temperature measurement using three DS1621 digital sensors, and a PIC16F877A microcontroller
Source: Own Elaboration, electronic diagram obtained with PROTEUS ISIS environment

In the I2C serial communication, the three DS1621 digital sensors were used as slaves, while the PIC16F877A microcontroller was used as the master. Table 2 shows the addresses of the digital sensors in slave mode, used to communicate the DS1621 digital sensors with the PIC microcontroller.

Digital Sensor DS1621	Address in hexadecimal format
Sensor A	$0 \times 00h$
Sensor B	$0 \times 01h$
Sensor C	$0 \times 02h$

Table 2 Hexadecimal addresses used to communicate the digital sensors with the PIC16F877A microcontroller
Source: Own Elaboration

The PIC microcontroller terminals used in the I2C serial communication were RC3/SCL and RC4/SDA. With the idea of connecting the LM35 and TMP36 analogue sensors and the three DS1621 digital sensors to the same microcontroller at a later stage, an LCD display was connected to port C of the PIC microcontroller as shown in figure 3.

Stage 3: Temperature measurement with the analogue and digital sensors in one electronic circuit

In this stage, the analogue and digital sensors used in the electronic circuits of figures 2 and 3 were connected to a single PIC microcontroller. In another new graphical work environment in ISIS, the electronic circuit in figure 4 was simulated.

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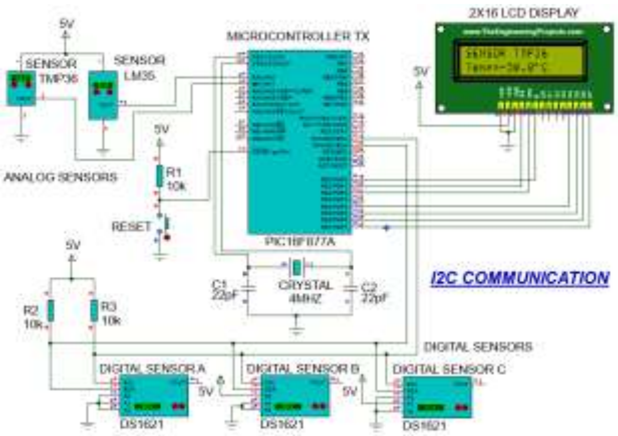

Figure 4 Temperature measurement with DS1621 digital sensors, LM35 and TMP36 analogue sensors, and the PIC16F877A microcontroller.
Source: Own Elaboration, electronic diagram obtained with the PROTEUS ISIS graphical environment

Figure 5 shows the variables used in the C language program code of the PIC microcontroller to store the temperature values of the analogue and digital sensors.

```
char string[6];
float Temperature1, Teemperature2;
float Temperature3, Temperature4;
float Temperature5;
```

Figure 5 Floating type variables used in the CCS Compiler to store temperature values obtained from analogue and digital sensors
Source. Own Elaboration

The variables Temperature1 and Temperature2 were used to store the temperature values in degrees Celsius (°C) of the analogue sensors. The Temperature1 variable was used to store the temperature values of the LM35 and Temperature2 for the TMP36. The variables Temperature3, Temperature4 and Temperature5 were used to store the temperature values in degrees Celsius (°C) of the DS1621 digital sensors. The variable Temperature3 was used to store the temperature values for digital sensor A, Temperature4 for digital sensor B and finally Temperature5 for digital sensor C.

Stage 4: Unidirectional point-to-point wired communication

Before simulating wireless communication with the XBEE modules in PROTEUS, tests were performed to send point-to-point data in one direction only in a wired fashion.

The electronic circuit in figure 4 was used as the transmitter circuit and another electronic circuit with a PIC16F877A microcontroller and an LCD display was used as the receiver circuit. In figure 6, a wire is connected from the RC6/TX terminal of the transmitter circuit's PIC microcontroller to the RC7/RX terminal of the receiver circuit's PIC microcontroller to perform the wired communication.

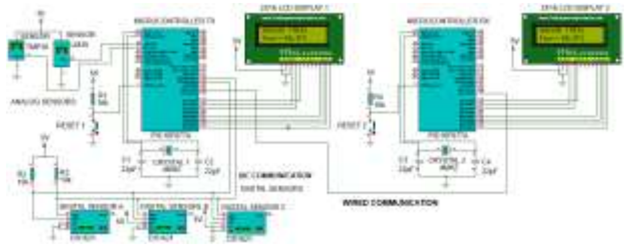

Figure 6 Unidirectional point-to-point wired communication between two electronic circuits with PIC16F877A microcontrollers
Source: Own Elaboration, electronic diagram obtained with PROTEUS ISIS environment

On the LCD displays connected to the PIC microcontrollers, the temperature value of the analogue sensor TMP36 is displayed. In this communication, the PIC microcontroller in the transmitter circuit sends the temperature data via asynchronous serial communication and displays it on the LCD, and the PIC microcontroller in the receiver circuit receives the temperature data and displays it on the LCD.

Focusing exclusively on debugging the program codes of the microcontrollers, so that they communicate properly with each other, was the reason for simulating the wired communication before simulating the wireless communication with the XBEE modules in PROTEUS.

In the wired simulation, before sending the temperature data from the transmitter circuit to the receiver circuit, each temperature data in floating format (number with decimal point) was converted to a six-element character string. As shown in Figure 7, the first five positions of the string were used to store the temperature data in character form, and the last position was used to assign an identifier character.

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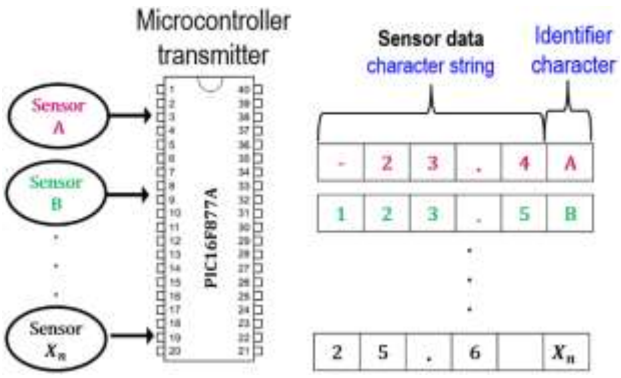

Figure 7 Storage of temperature data from analogue and digital sensors in a six-character string
Source: Own Elaboration

Each of the sensors connected to the transmitter circuit's PIC microcontroller was assigned an identifier character, which was assigned in the fifth position of each sensor's temperature data character string. Table 3 shows the identifier character assigned to each sensor.

LM35 sensor characters					*Identifier*
C_0	C_1	C_2	C_3	C_4	*A*
TMP36 sensor characters					***Identifier***
C_0	C_1	C_2	C_3	C_4	*B*
DS1621A sensor characters					***Identifier***
C_0	C_1	C_2	C_3	C_4	*C*
DS1621B sensor characters					***Identifier***
C_0	C_1	C_2	C_3	C_4	*D*
DS1621C sensor characters					***Identifier***
C_0	C_1	C_2	C_3	C_4	*E*

Table 3 Assignment of the identifier character for each of the digital and analogue sensors
Source: Own Elaboration

Figure 8 shows the instructions that were used in the program code of the transmitter circuit's PIC microcontroller to form the character string for each of the temperature data.

```
sprintf(string,"%1.1f",Temperature1);
string[5] = 'A';
SEND_SERIAL_DATA();
```

Figure 8 Instructions of the program code in C language of the PIC microcontroller of the transmitter circuit, to form the string of characters of each temperature data
Source: Own Elaboration

The instruction sprint *sprintf(string,"%1.1f",Temperature1)* was used to convert a temperature data into character format. With the instruction string[5] = 'A' the identifier character was assigned to the fifth position of the character string.

UART asynchronous serial communication was used to send the temperature data in character string format from the *transmitter circuit* to the *receiver circuit*. Figure 9 shows the transmission of a character string by asynchronous serial communication of a temperature data.

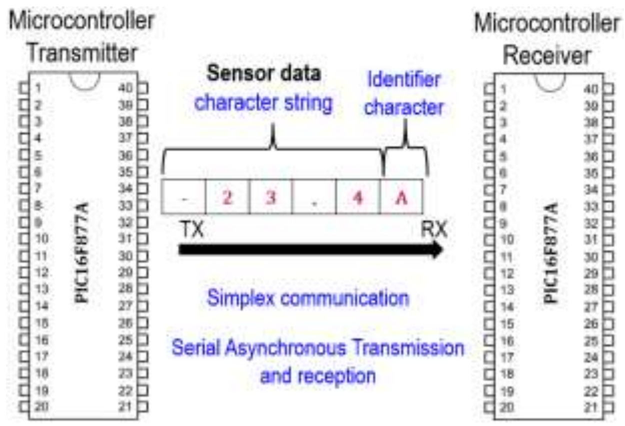

Figure 9 Temperature data sent asynchronously serially from the transmitting circuit's PIC microcontroller to the receiving circuit's PIC microcontroller
Source: Own Elaboration

The RC6/TX terminal of the physical UART port of the transmitter circuit's PIC microcontroller was used to send the characters of each temperature data. In the PIC microcontroller of the receiver circuit, the *RC7/RX* terminal was used to receive the characters of each temperature data.

In figure 10, the instructions inside the *void* function *SEND_SERIAL_DATA()* were used in the program code of the transmitter circuit's PIC microcontroller to send by asynchronous serial communication the characters of each temperature data.

```
void SEND_SERIAL_DATA()
{
 for (i = 0; i <= 5; i++)
    {
       putc(string[i]);
       delay_ms(100);
    }
}
```

Figure 10 Instructions for sending the six characters of each temperature data via asynchronous serial communication
Source: Own Elaboration

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The instruction putc *putc(string[i])*, was used to send through the *RC6/TX* terminal of the transmitter circuit's PIC microcontroller, the six characters of each temperature data. The characters were sent one by one with a delay of 100 milliseconds.

When receiving the temperature data with the receiving circuit's PIC microcontroller, the six characters were received one by one via the UART interrupt, and then transformed to floating-point data, as shown in figure 11.

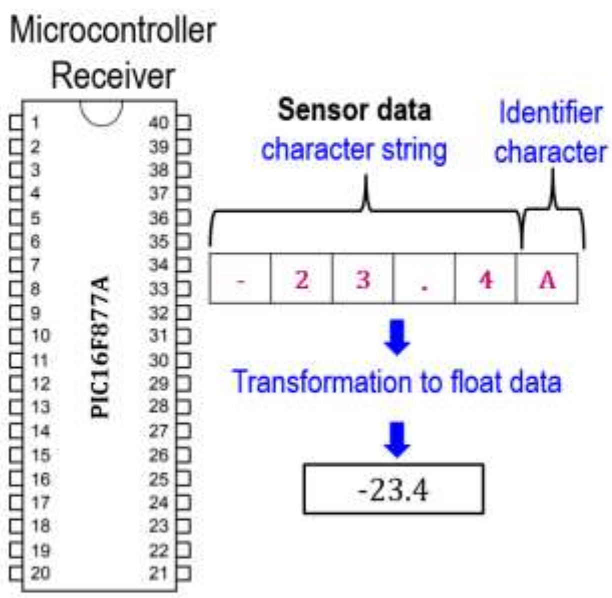

Figure 11 Representation of the reception and transformation of the character string of a temperature data to a floating point number
Source: Own Elaboration

In the program code of the receiving circuit's PIC microcontroller, the variable *string[i]* was declared to store the characters received. The variable i was declared as a global variable and assigned an initial value of zero (i = 0). Figure 12 shows the flowchart of the programming algorithm for character reception, conversion to floating data and display on the LCD screen.

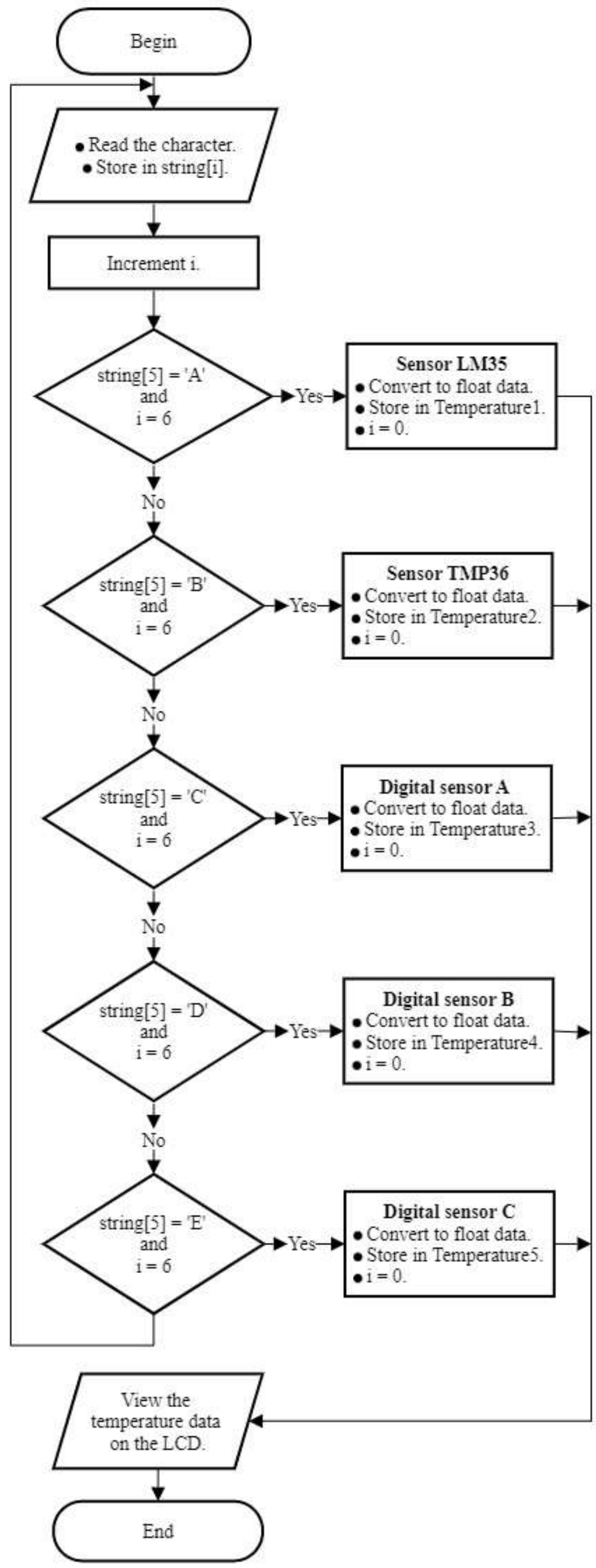

Figure 12 Flowchart of the programming algorithm for the PIC16F877A of the receiver circuit
Source: Own Elaboration, flowchart developed with smartdraw online

In the program code for the PIC16F877A *receiver circuit*, the interrupt function of the UART receiver was used to receive the characters via the *RC7/RX* terminal, and the instructions of the main function of the program code were used to display the temperature data of the analogue and digital sensors on the LCD.

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Figure 13 shows the interrupt function *RDA_isr()*, used to receive the characters by the *RC7/RX* terminal. The instructions within this function were used to receive, store, and convert to floating data, and identify which sensor the characters belong to.

```
RDA_isr()
{
   string[i] = getc();
   i++;
     if (string[5] == 'A' && i == 6)
      {
        i = 0;
        Temperature1 = atof(string);
      }
}
```

Figure 13 Interrupt function to receive, store, convert to a floating point number, and identify which sensor the string belongs to
Source: Own Elaboration

The instruction *string[i] = getc()* was used to wait for characters from the *RC7/RX* terminal and store them in the variable *string[i]*. With the control statement and the evaluation of the expression *if(string[i] == 'A' && i == 6*) the identification of the characters belonging only to the LM35 sensor was made. The instruction *Temperature1 = atof(string)* was used to convert the characters of the temperature data from the LM35 sensor to a floating point number and store it in the variable *Temperature*1. The instructions to convert the temperature characters to a floating point number for the TMP36 sensors and the other DS1621 digital sensors are not shown in Figure 13, but if they were implemented in this work, a control statement with its expression evaluation must be added inside the serial interrupt function *RDA_isr()*, to detect the characters of each sensor to be added to the unidirectional point-to-point communication.

Results

Stage 5: Unidirectional point-to-point wireless communication

Once stage 4 was completed, the next step was to connect the XBEE RF modules to the PIC microcontrollers. Figure 14 shows the connections of the XBEE modules to the PIC microcontrollers.

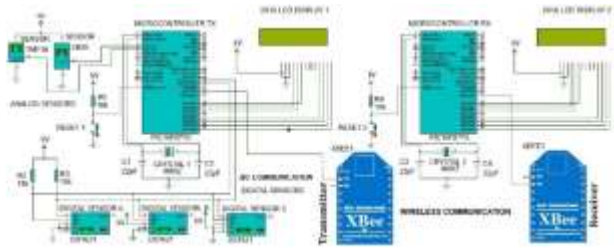

Figure 14 Connecting the XBEE modules to the terminals of the PIC16F877A microcontrollers for wireless communication
Source: Own Elaboration, electronic diagram obtained with the PROTEUS ISIS graphical environment

In the transmitter circuit, the TX terminal of the XBEE module was connected to the RC6/TX terminal of the PIC microcontroller. In the receiver circuit, the RX terminal of the XBEE module was connected to the RC7/RX terminal of the PIC microcontroller.

To achieve wireless communication in PROTEUS, the virtual serial port emulator VSPE version 0.938.4.846 was used to emulate the connection between two virtual ports. Figure 15 shows the component editing window to edit the characteristics of the XBEE module of the *transmitter circuit*.

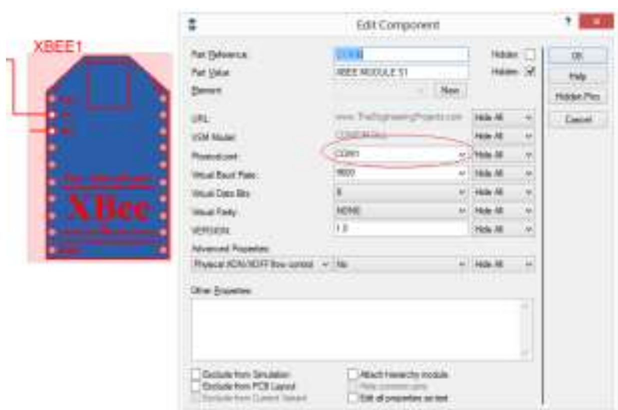

Figure 15 Editing the XBEE module characteristics of the transmitter circuit in the component edit window
Source: Own Elaboration, figure obtained from PROTEUS ISIS environment

For the XBEE module of the *transmitter circuit*, the virtual COM1 port was chosen, with a transmission speed of 9600 bits/second.

Figure 16 shows the component editing window for editing the characteristics of the XBEE module of the *receiver circuit*.

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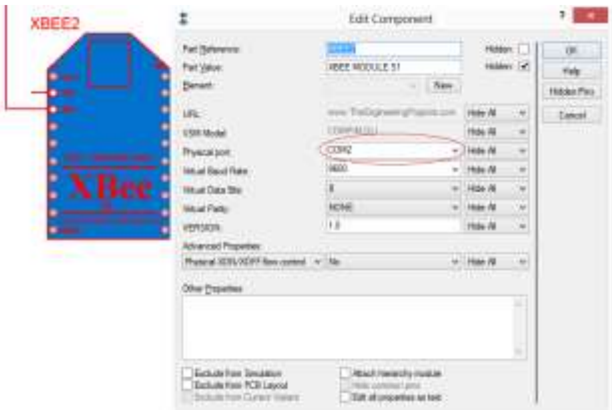

Figure 16 Editing the characteristics of the XBEE module of the receiver circuit in the component editing window
Source: Own Elaboration, figure obtained from PROTEUS ISIS environment.

In the component edit window, the virtual COM2 port with a baud rate of 9600 bits/second was chosen. The baud rate between the transmitter circuit and the *receiver circuit* must be equal for communication between them.

To emulate the virtual ports COM1 and COM2, in the main window of the virtual serial port emulator VSPE, a new device was selected to enter the device creation wizard, as shown in Figure 17.

Figure 17 Creating a new device in the virtual serial port emulator VSPE
Source: Own Elaboration, figure obtained from the VSPE emulator.

In the specify device type window, shown in Figure 18, the *pair* option was chosen, which is to connect two virtual serial ports.

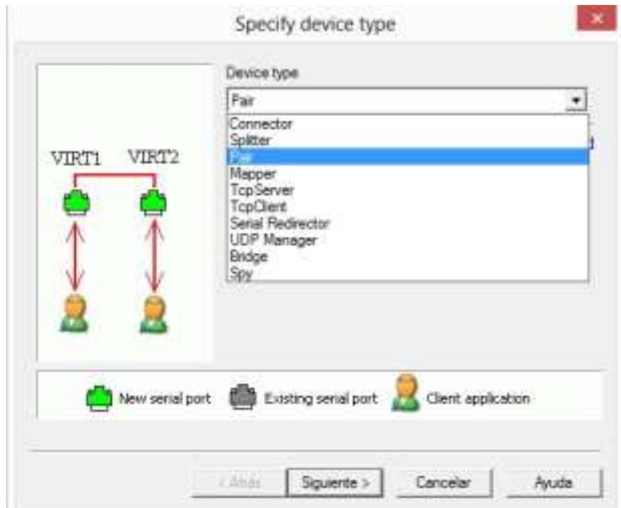

Figure 18 Creation of two virtual ports in the VSPE emulator
Source: Own Elaboration, figure obtained from the VSPE emulator.

In the window to specify the device characteristics, the COM3 and COM4 ports were chosen, taking into account that the same ports selected in the computer equipment should not be used (figure 19).

Figure 19 Selection of ports in VSPE to carry out emulation
Source: Own Elaboration, figure obtained from the VSPE emulator.

Finally, in the *emulation started* window, shown in Figure 20, the status of the virtual ports will appear, indicating that the ports selected in PROTEUS can be emulated.

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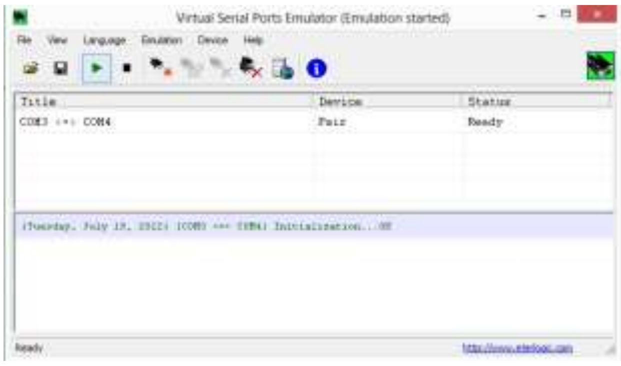

Figure 20 Status of the virtual ports in the emulation started window
Source: Own Elaboration, figure obtained from the VSPE emulator

The analogue and digital sensors were set to different temperature values to verify wireless point-to-point communication. Table 4 shows the temperature values at which the sensors were set to perform the communication test.

Analog Sensor	Temperature value
LM35	27 °C
TMP36	-40 °C
Digital Sensor DS1621	
A	35 °C
B	40 °C
C	27 °C

Table 4 Temperature values for testing the wireless communication in the simulation
Source: Own Elaboration

Figure 21 shows the temperature value of the LM35 analogue sensor during one-way wireless communication.

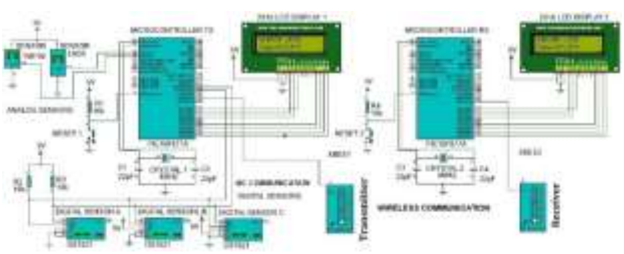

Figure 21 Wireless simulation: LM35 sensor data sent by the transmitter circuit and received by the receiver circuit
Source: Own Elaboration, figure obtained from PROTEUS ISIS environment.

On the LCD screen of the transmitter circuit, the temperature data were displayed after being sent. On the LCD screen of the receiver circuit, the temperature data were displayed after being received.

Figure 22 shows the temperature of the TMP36 sensor in the transmitter and receiver circuits.

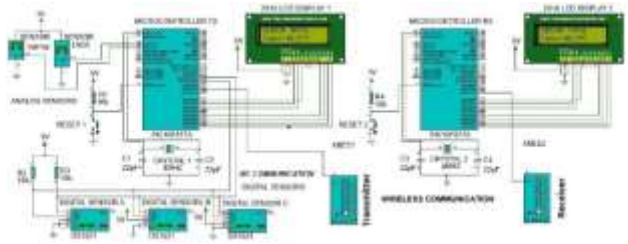

Figure 22 Wireless simulation: TMP36 sensor data sent by microcontroller TX and received by microcontroller RX
Source: Own Elaboration, figure obtained from PROTEUS ISIS environment.

Figure 23 shows the temperature of the digital sensor A DS1621, after being sent by the transmitter circuit and received by the receiver circuit.

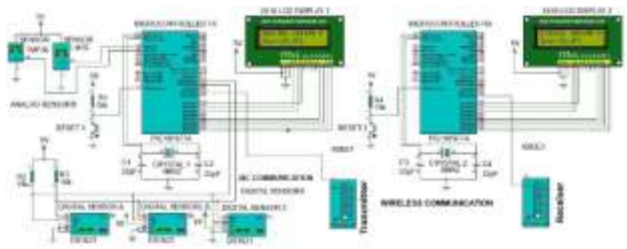

Figure 23 Wireless simulation: data from digital sensor A DS1621 sent by the transmitter circuit and received by the receiver circuit.
Source: Own Elaboration, figure obtained from PROTEUS ISIS environment.

Figure 24 shows the temperature of the digital sensor B DS1621, when it is sent by the transmitter circuit and received by the receiver circuit.

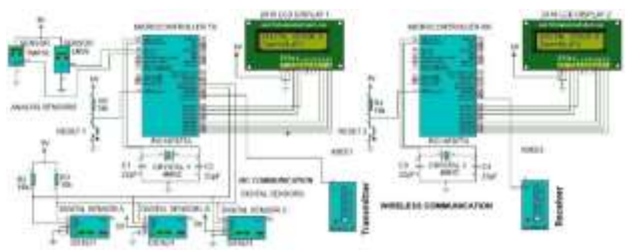

Figure 24 Wireless simulation: data from digital sensor B DS1621 sent by the transmitter circuit and received by the receiver circuit.
Source: Own Elaboration, figure obtained from PROTEUS ISIS environment

Figure 25 shows the temperature of the digital sensor C DS1621 during wireless point-to-point communication.

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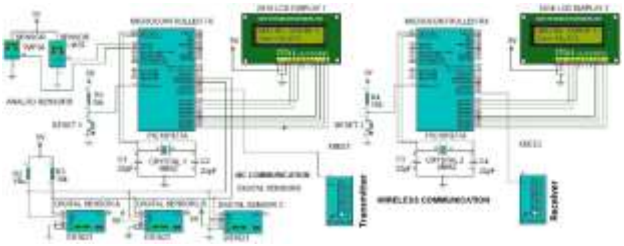

Figure 25 Wireless simulation: data from digital sensor C DS1621 sent by the transmitter circuit and received by the receiver circuit.
Source: Own Elaboration, figure obtained from PROTEUS ISIS environment

Finally, the RXD terminal of the VIRTUAL TERMINAL instrument was connected between the RX terminal of the XBEE module and the RC7/RX terminal of the PIC microcontroller of the receiver circuit to display the characters sent asynchronously from the PIC microcontroller of the transmitter circuit to the PIC microcontroller of the receiver circuit. The reception of the characters is shown in figure 26.

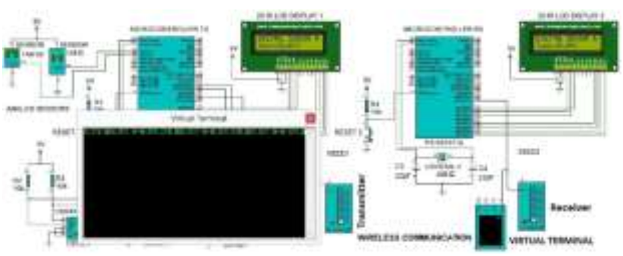

Figure 26 Display of the temperature data in character format with the VIRTUAL TERMINAL instrument
Source: Own Elaboration, figure obtained from PROTEUS ISIS environment

Acknowledgement

We are grateful for the support granted by the Polytechnic University of Juventino Rosas, which through the department of Network and Telecommunications Engineering provided the facilities for students to participate and contribute to this technological development work. We are also grateful for the collaboration of the authors of this article who participated in the work.

Conclusions and future work

In the simulation, asynchronous serial communication was implemented to send only the temperature data from five sensors of the *transmitter circuit* to the *receiver circuit*, however, the data sent can be of other variables such as: relative humidity, illumination, and CO_2.

The program code of the receiver circuit's PIC microcontroller can be modified to receive and identify data from more than five sensors.

In this work, a programming algorithm was designed to receive and identify data from different sensors. No matter if the data is from a temperature, relative humidity, illumination or CO_2. sensor, all data will be received with the *receiver circuit* in character packets. The importance to be given in this work, is that any data received by the receiver circuit is very well identified, since in future simulations it is intended to use up to 20 sensors approximately.

The PIC microcontroller in the *transmitter circuit* measured the temperature of two analogue and three digital sensors, and then the temperature data were displayed on an LCD screen and sent to the receiver circuit. In future work, it is recommended that analogue and digital relative humidity and illumination sensors be connected to the *transmitter circuit's* PIC microcontroller to simulate the measurement, display and sending of data. The sensor libraries available in the PROTEUS software should be used.

In this wireless communication, the *receiver circuit* performed the reception of the temperature variables, but did not implement the control of an actuator. The programming algorithm of the PIC microcontroller of the *receiver circuit* was designed only to receive by serial communication, identify and display on an LCD screen the data from the digital and analogue sensors. Future work can connect output peripherals to the PIC microcontroller, and modify the program code to control actuators based on a decision made by the received data.

The information exchange between the transmitter circuit and the *receiver circuit* was unidirectional. In the next phase of the simulation it is intended to implement a bidirectional wireless communication, where both electronic circuits have the role of transmitting and receiving data. In the bidirectional communication, the receiver circuit can respond to the *transmitter circuit* when it wants to receive data and when it does not, or the *receiver circuit* can tell the transmitter circuit that it only needs data from certain sensors.

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In future work, it is intended to implement a wireless sensor network (WSN) with XBEE technology. The nodes of the wireless network will be sensors connected directly to the terminals of an XBEE module, to measure environmental variables in a timely manner. The coordinator in the wireless network will be a PIC microcontroller with an XBEE module as main devices. where it is available. The coordinator will strategically receive all the data sent by the nodes.

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PID Instrumented Control Elements Estimation Based on Probabilistic Methods

Estimación de elementos de control PID instrumentado basado en métodos probabilísticos

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Abstract

The applications of a controller, such as a control valve, require robust control schemes for all the variables that exist. Have a functional prototype of the automatic systems that operate in the Ingeniero Antonio M. Amor Refinery, to facilitate the movement of the final elements and obtain greater control of the events that occur in the process plants. The behavior analysis for a control valve was performed using probabilistic methods, using the MATLAB Toolbox. In this document it can be seen that a neural network can be trained to provide the coefficients of a PID controller, where the response is close to that of an analog PID controller with a known set point.

Neural Networks, PID Control, Automatic Systems

Resumen

Las aplicaciones de un controlador, tal como lo es en una válvula de control, requieren de esquemas de control robustos para considerar todas las variables posibles que existan. Este articulo, propone tener un prototipo funcional de los sistemas automáticos que operan en la Refinería Ingeniero Antonio M. Amor, para facilitar el movimiento de los elementos finales y obtener un mayor control de los eventos que suceden en las plantas de proceso. El análisis de comportamiento para una válvula de control se realizará mediante métodos probabilísticos, utilizando las Toolbox de MATLAB. En este documento se demostrará que una red neuronal puede ser entrenada para proporcionar los coeficientes de un controlador PID, en donde la respuesta se aproxime a la de un controlador PID analógico con set point conocido.

Redes Neuronales, Control PID, Sistemas Automáticos

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Introduction

This project presents background research work and partial results on PID controllers using BP neural networks. Industrial control systems are becoming a trend in describing the networks, hierarchical control layers and communication capabilities of a system through software tools, intelligent sensors and methods designed for fault tolerance and handling of safety critical problems. The structure is established by proportional, integral and derivative (PID) controllers. Due to the practicality of PID controllers, they have become industry standard tools and have well-established rules for tuning controller parameters in real-time applications.

The purpose of control objects is to have high inertia, nonlinear characteristics and an uncertain disturbance factor. Optimization of PID parameters is required to improve the performance of the controllers. There are several studies involved in parameter optimization, some of them: in [1] an adaptive learning algorithm based on genetic algorithms is shown to obtain automatic tuning in PID controllers, aiming to achieve optimal performance. In [2], based on genetic algorithms, fuzzy control rules and membership function have been optimized. In [3], a neural network controller and a fuzzy logic controller are combined.

Neural network technology has been applied in the field of control systems, energy management, fault prediction and diagnosis, identification and optimization. The algorithm uses feedforward neural networks, which was frequency optimized in [4]. In [5] they develop a neural PID control algorithm module, which shows that the neural PID controller strategy is more robust than the conventional PID controller.

The objective of the project is to realize a control system of a control valve for the Engineer Antonio M. Amor Refinery, through a behavioral analysis by means of probabilistic methods using neural networks. In the simulation and optimization of the algorithms it is sought that the PID controller using a neural network has the capacity of self-adaptation.

Methodology

Measurements

In order to know the current operation of the control valve and the conditions in which it is found, a visit was made to the Ingeniero Antonio M. Amor Refinery in the city of Salamanca.

For data collection, three different control valves were chosen, from each one approximately 21,600 data were extracted, in an interval of eight hours, taking data in an interval of 1 second. The data readings came from various pressure indicating controllers (PICs). In the visit to the refinery, it was possible to know the operation of the valves, and we realized that the adjustment of the valves is still manual, which meets the objectives of the project, which is to make a control system in which a control valve is self-adjusting, this would save time and costs for the refinery.

Configuration of a PID control system using neural networks

The PID controller using neural network is the combination of a neural network and a conventional PID control, which combines the excellence of both PID controller and neural networks. The structure of the neural network control system consists of the PID controller using a neural network and a nonlinear prediction model (NNM) as shown in Figure 2.

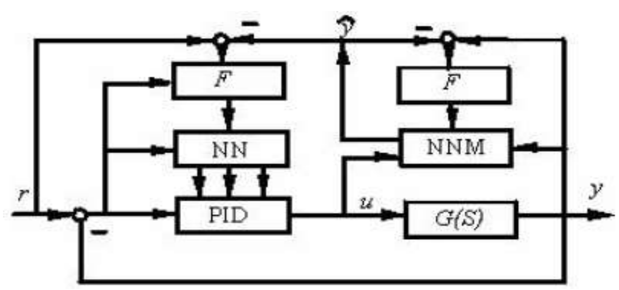

Figure 2 PID control system using a neural network

Where r is the input configuration, G(s) is the controller object, y is the actual output, u is the variable controller, yˆ is the prediction of y, NNM represents the neural network linear prediction model of yˆ, NN represents the neural network and F represents the learning algorithm.

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Algorithm process

Para este proyecto se usará una red neuronal de retroceso con tres capas como se muestra en la

Figure 3, which has M input neurons, Q hidden neurons and three output neurons.

The output of the feedforward neural network are the setting of the three PID controller parameters (k_P, k_I y k_D), which cannot be negative, the activation function is a Sigmoid function.

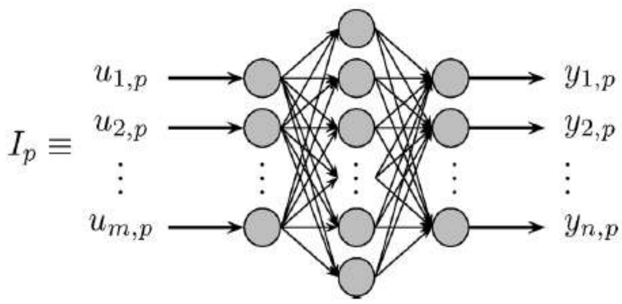

Figure 3 Configuration of the backtracking neural network

Results

The first thing that was done was to observe the behavior of the data obtained from the control valves, the graphs show a similar behavior of each data collection, being a linear behavior until a stabilization point as shown in Figure 4.

Figures 5 to 7 show the results of the neural network training simulation. The performance results of a trained neuron with 1 input layer, 10 hidden layers and one output layer are shown for each of the data sets obtained from the control valves. The graphs show the performance of the network based on epochs, which are periods of time where the performance of the network is analyzed.

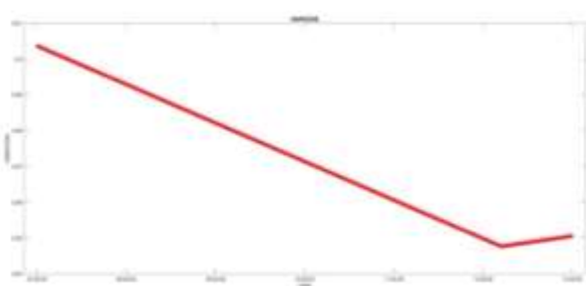

Figure 4 Behavior of data collected from control valves

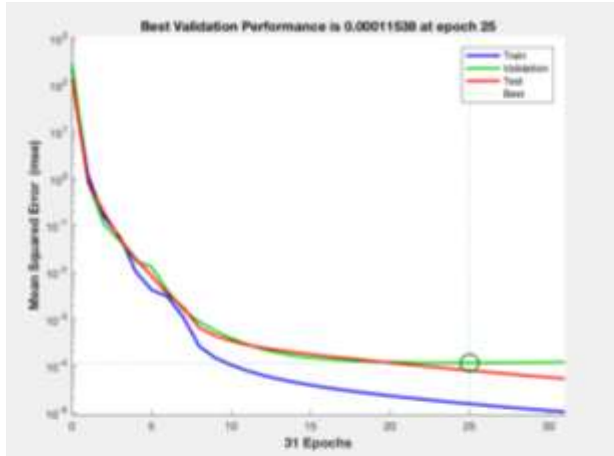

Figure 5 Results of the first data set. It is observed that the neural network simulation reaches its best performance at 25 epochs.

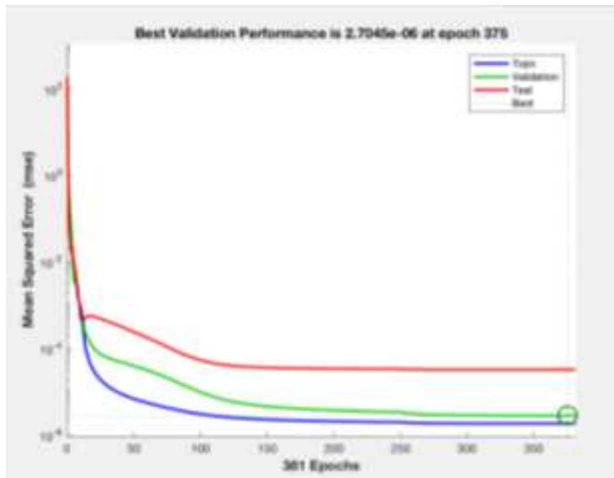

Figure 6 Results of the second data set. It is observed that the neural network simulation reaches its best performance at 375 epochs

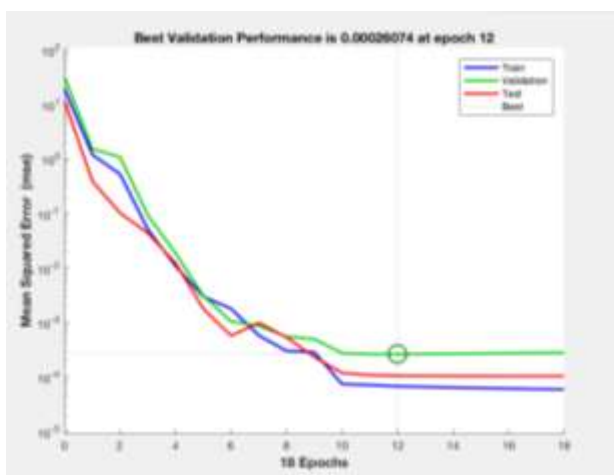

Figure 7 Results of the third data set. It is observed that the neural network simulation reaches its best performance in 12 epochs

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Conclusions

The project has shown the various applications of neural network control systems that help in the optimization of different systems. The various parameters that compose the control system have to be taken into account to obtain better performance and accuracy that are adjusted during the training stage of the neural network, however, the robustness levels have to be taken into account when the parameters of the PID controller change.

The advantages offered by a neural network PID controller are the self-study and self-adaptation capabilities, which facilitates faster responses and better performances.

Contribution

The usefulness of the results of the study is to develop and test a new methodology based on probabilistic methods for a controller, such as a control valve, that allows the robust control of the different existing variables that occur in process plants.

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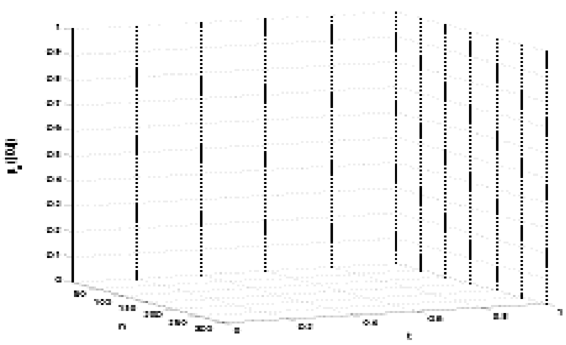

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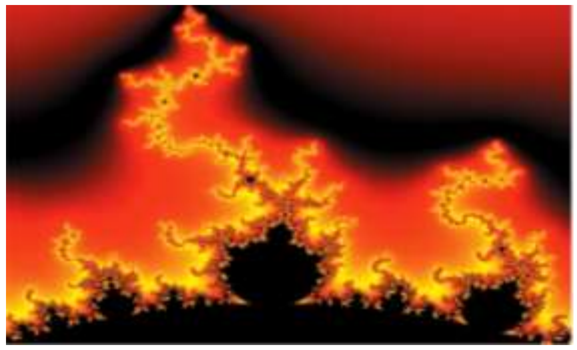

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