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APPLICATION OF THE HONEY BADGER ALGORITHM IN THE COOLING REGULATION OF THERMOELECTRIC CELLS

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ABSTRACT.

This article presents an algorithm based on swarm intelligence called the Honey Badger Algorithm, a small carnivorous mammal that has two attributes that characterize it: its strong sense of smell to locate food and claws powerful enough to dig in order to get its food. The computational implementation of this algorithm bases its operation on a cardioid function. As a case study, a classic regulator is designed, specifically a PID applied to the temperature control of a thermoelectric cell. The results obtained with these heuristics are compared, according to the specialized literature, with a regulator designed by means of an algorithm called Coronavirus herd immunity optimizer. The comparison shows that the Honey Badger Algorithm significantly reduces some performance indices such as mean square error with fast convergence.

Keywords: Honey Badger Algorithm, Thermoelectric cell, Optimization

ABSTRACT.

En este artículo se presenta un algoritmo basado en inteligencia de enjambre llamado Algoritmo de Tejón Mielero, un pequeño mamífero carnívoro que tiene dos atributos que lo caracterizan: su fuerte sentido del olfato para localizar comida y garras lo suficientemente potentes como para cavar con el fin de obtener su alimento. La implementación computacional de este algoritmo basa su funcionamiento en una función cardioide. Como caso de estudio, se diseña un regulador clásico, concretamente un PID aplicado al control de temperatura de una célula termoeléctrica. Los resultados obtenidos con estas heurísticas se comparan, según la literatura especializada, con un regulador diseñado mediante un algoritmo denominado Optimización de inmunidad de rebaño al Coronavirus . La comparación muestra que el algoritmo del Tejón Melero reduce significativamente algunos índices de rendimiento, como el error cuadrático medio, con una convergencia rápida.

Palabras clave: Algoritmo de Honey Badger, Célula termoeléctrica, Optimización

1. INTRODUCCIÓN

The components of an aerospace (AV) vehicle, regardless of whether they are manned or unmanned, have a temperature range, which is necessary to guarantee operating and survivability conditions during all phases involved in a space mission. The temperature of an AV can be described in general terms by means of the laws of conservation of energy for controlled volumes described as , where it represents the thermal energy absorbed from external sources such as the sun, the heat of the sun reflected on the earth's surface, the infrared heat emitted by the earth, is the heat radiated by the AV while it is the heat generated by the operation of the components associated with the AV.$\dot{E}_{in} - \dot{E}_{out} + \dot{E}_{gen} = \dot{E}_{stored}\dot{E}_{in}\dot{E}_{out}\dot{E}_{gen}$. [1]
To preserve the equality expressed in it is necessary to implement some cooling method such as those shown below, which are called passive, since they do not depend on an electrical source to function: $\dot{E}_{in} - \dot{E}_{out} + \dot{E}_{gen} = \dot{E}_{stored}$
Algunos métodos de enfriamiento son [2]:

i. Thermal Control Coatings
ii. Thermal belts
iii. Thermal blinds
iv. Deployable radiators
v. Phase Change Materials
vi. Thermal Switches

When precise temperature control is required, they use methods supported by active elements, in which an external power source is necessary, this type of method is adjustable to platforms such as SmallSat and CanSat. These active cooling elements are listed below:

i. Electric heaters based on a resistor
ii. Miniature Cryogenic Refrigerators
iii. Refrigerant fluid recirculation systems
iv. Thermoelectric Cell

TEC Thermoelectric Cells are semiconductor devices whose operation is theoretically supported by the Peltier effect, which describes the release or absorption of heat at the junction of two semiconductor materials through which an electric current circulates. The amount of heat emitted or absorbed is determined by the direction of the current present in the junction, it is proportional to the electric current by means of the Peltier coefficient π i.e., one of the junctions heats up while the other cools down [3], this can be seen in Figure 1.
Considering room temperature as constant, it is possible to reduce the mathematical model of a thermoelectric cell to a mathematical expression in terms of the complex variable s shown in equation 1 [4]

$$G(s) = -6.4061\left(\frac{0.064s + 0.00854}{s^2 + 0.5964s + 0.00855}\right) \quad (1)$$

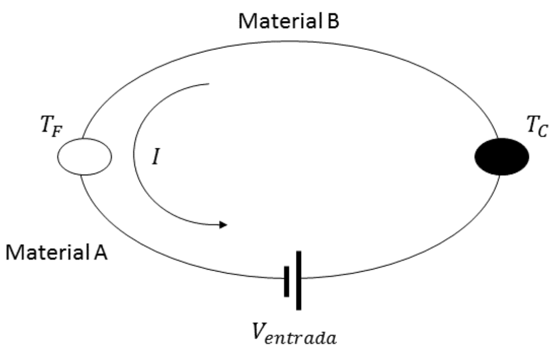

Fig. 1.- Peltier effect [3].

The response to a step-type electrical stimulus, applied to equation 1, is shown in Figure 1. The response of a ECT, shown in Fig. 2, can be modified by means of automatic control techniques, as shown by the state of the art summarized in Table 2.

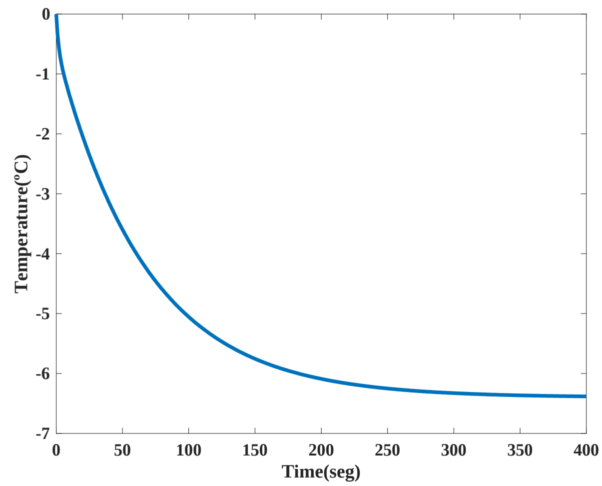

Fig. 2 Thermoelectric Cell Response

The response of a Thermoelectric Cell can be modified by means of control techniques, this has been extensively explored in several works of the state of the art such as in [4][5][6], where heuristic methods are applied to tune gains or fuzzy sets. The most current case of tuning of a regulator is addressed in [7] where a new heuristic supported by the herd immunity that was presented by the appearance of the Covid 19 pandemic is used, in this case the heristics is called Coronavirus herd immunity optimizer, but overlooks a method called Honey Badger Algorithm, that it is also a heuristic method classified within swarm intelligence and that its use is extended in the design of regulators applied to various areas. **Therefore, the present contribution aims to tune the gains of a controller applied to a Thermoelectric Cell by means of a Honey Badger Algorithm**

2. THEORETICAL SUPPORT

Softcomputing is a set of techniques of artificial intelligence, which are inspired by natural phenomena, examples of them are Artificial Neural Networks (ANN), Fuzzy Logic (FL) and Heuristic Algorithms (HA), the latter are a method of solution for optimization problems, which can be defined, as a quaternary, shown in equation 2 [8].$P = (\vec{x}, f, SS, F)$

$$P = \begin{cases} opt:\ f(\vec{x}) \\ s.a \\ \vec{x} \in F \subset SS \end{cases} \quad (2)$$

Where is the solution vector that maximizes or minimizes, according to case a $\vec{x} = (x_1, x_2, x_3, \ldots x_n) f$, which is a mathematical function determined by the problem to be solved, the set of feasible solutions and SS the space of solutions. When it is stated that it is a combinatorial optimization problem while for it is a numerical problem $P\ \vec{x} \in \mathbb{Z}\ \vec{x} \in\ \mathbb{R}$. There are two

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alternatives for solving optimization problems, the first consists of deterministic methods, which are procedures or mathematical models defined with certain conditions. The second alternative, which is effective for problems whose mathematical complexity is high, are Metaheuristic algorithms, which are stochastic methods supported by principles inspired by nature. Figure 3 shows a classification of Metaheuristic algorithms in terms of their inspiration

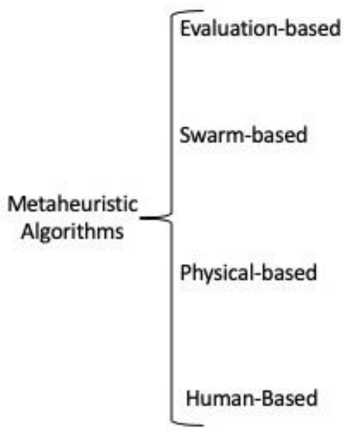

Fig. 3 Classification of Metaheuristic Algorithms

Specifically, the first HA was the Genetic Algorithm (GA), proposed by John Holland in the 1950s. The theoretical support of this algorithm is found in the works on the Laws of Inheritance proposed by Gregory Mendel and Charles Darwin's Theory of the Evolution of Species [7].

The genetic algorithm (Algorithm 1) developed by John Holland has been used as a basis for the development of various heuristics, which have the purpose of better searching for optimal values or reducing the number of iterations. This is justifiable by David Wolpert and William Macready with the No Free Lunch Theorem, in which the non-existence of a universal solution algorithm for all combinatorial or numerical optimization problems is determined. [8]

Algorithm 1 *Evolutionary Algorithm*

Initialize population
Calculate fitness $f(\vec{x}_i)$
    While i < maximum number of iterations **do**
        Select parents
        Recombine pairs of parents
        Evaluate new candidates
        Select individual for the next iteration
        i++
    end
end

Swarm Intelligence (SI) is a category of metaheuristic algorithms that are supported in the collective behavior, whether migratory or predatory, of certain animal societies such as ants, bats, schools of fish and flocks of birds, this is emulated by computational agents [8].

One of the recently developed swarm intelligence algorithms is the Honey Badger Algorithm (HBA), a metaheuristic method that is inspired by the way the honey badger, a carnivorous mammal of the marmot family that inhabits regions of Africa, the Middle East and India, gets food.

The HBA emulates the foraging behavior of the honey badger, which to locate its food uses its nose to approach its prey, when locating it moves around it to select the appropriate place to dig with its claws and catch it (this is known as the digging mode). There is a second alternative for searching for food, called honey mode, in which the honey badger follows a bird that guides it to the honey to take directly from the hive [10].

The first versions of the HBA were generated in 2023, which consists primarily of the generation of the population which is shown in equation 3 and is carried out randomly [10].

$$Population = \begin{pmatrix} x_{11} & \cdots & x_{1D} \\ \vdots & \ddots & \vdots \\ x_{n1} & \cdots & x_{nD} \end{pmatrix} \quad 3$$

Where i th position of honey badger $x_i = [x_i^1, x_i^2, \dots, x_i^D]$. Subsequently, once the population has been defined, it is important to calculate a parameter called intensity, which is mathematically defined in equation 4 [10].

$$I_i = r_2 \times \frac{S}{4\pi d_i^2} \quad 4$$

Where S is the force of concentration, and mathematically it is defined as $S = (x_i - x_{i+1})^2$, On the other hand, d_i is the distance between the dam (x_{prey}) and the I-th badger (x_i), $d_i = x_{prey} - x_i$, r_2 It's a random number entre 0 and 1. Finally I_i it expresses the intensity of the smell that exists between the prey and the badger to be evaluated; If the smell is high, the movement will be fast and vice versa as shown in Figure 4 [10]

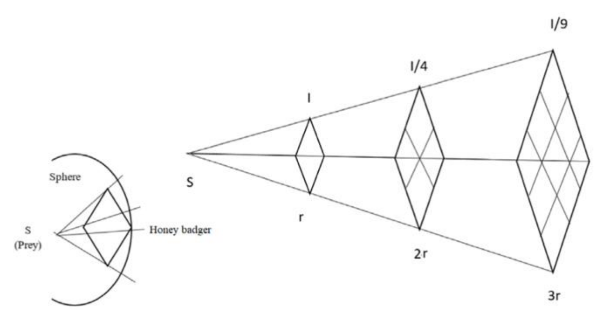

Fig. 4 Representation of the search for food

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The transition between the exploration of the algorithm's search space and the exploitation phase is controlled by time-varying randomization. This is defined by the fact that it decreases exponentially with respect to the number of iterations as shown in equation 4, α Where $C \geq 1$, (It is noteworthy that the literature considers $C = 2$), t is the current iteration and t_{max} the maximum number of iterations [10].

$$\alpha = C \times e^{\frac{-t}{t_{max}}} \quad (4)$$

To update the position of the badger (x_{new}) It is possible to resort to the similarity to the modes of digging and honey, for the digging phase it is possible to express the movement of the badger in terms of a cardioid, this is shown in equation 5 [10].

$$x_{new} = x_{prey} + F \times \beta \times I \times x_{prey} + F \times r_3 \times \alpha \times d_i \times |cos(2\pi r_4) \times [1 - cos(2\pi r_5)]| \quad (5)$$

Where x_{prey} it is the position of the dam, that is, the best position among all the possible solutions, $\beta \geq 1$ (the default value $\beta = 6$) Defines the ability to search for food d_i is the distance between badger and prey, r_3, r_4 y r_5 There are three random numbers between 0 and 1. I is calculated in equation 4. On the other hand, F controls the direction of the search and is determined by equation 6, to r_6 Random between 0 and 1 [10]

$$F = \begin{cases} 1 & if\ r_6 \leq 0.5 \\ -1 & else \end{cases} \quad (6)$$

The honey phase (another of the badger's foraging modes) can be simulated by means of equation 7, where r_7 is a random number between 0 and 1. HBA is shown in algorithm 2 [10]

$$x_{new} = x_{prey} + F \times r_7 \times \alpha \times d_i \quad (7)$$

Algorithm 2 *Evolutionary Algorithm*

Set parameters tmax , N, β, C.
Initialize population
Calculate fitness $f(\vec{x}_i)$
Save best position x_{prey} assign fitness to f_{prey}.
  While t ≤ t_{max} **do**
    Update α using (4)
    For $i = 1$ **to** N **do**
      Calculate I_i using (3)
      if $r < 0.5$ **then**
        Update x_{new} using (5)
      else
        Update x_{new} using (7)
      end if
    Evaluate new position and assign to f_{new}
      if $f_{new} \leq f_i$ **then**
        Set $x_i = x_{new} \wedge f_i = f_{new}$
        end if
      if $f_{new} \leq f_{prey}$ **then**
        Set $x_{prey} = x_{new} \wedge f_{prey} = f_{new}$
        end if
    end For
  end While Stop criteria satisfied

3. METHODOLOGY

Figure 5 shows the methodological scheme applicable to this proposal. First, it is necessary to calculate a target function, which allows the adjustment of the gains of a PID regulator applicable to the temperature control of a TEC. This is determined by some performance criteria from the error $e(t)$ estimate as shown in Table 1

Table 1 Criteria from the error $e(t)$ estimate

ITAE	Integral of time multiplied Absolute Error Criterion	$ITAE = \int_0^T t\lvert e(t)\rvert dt$
IAE	Integral Absolute Error Criterion	$IAE = \int_0^T \lvert e(t)\rvert dt$
ITSE	Integral of time multiplied squared error criterion	$ITSE = \int_0^T te^2(t)dt$
ISE	Integral square-error criterion	$ISE = \int_0^T e^2(t)dt$

In such a way that the fitness function is defined by equation 8

8

$$f_{fitness} = \frac{1}{1 + ITAE + IAE + ITSE + ISE} \quad (8)$$

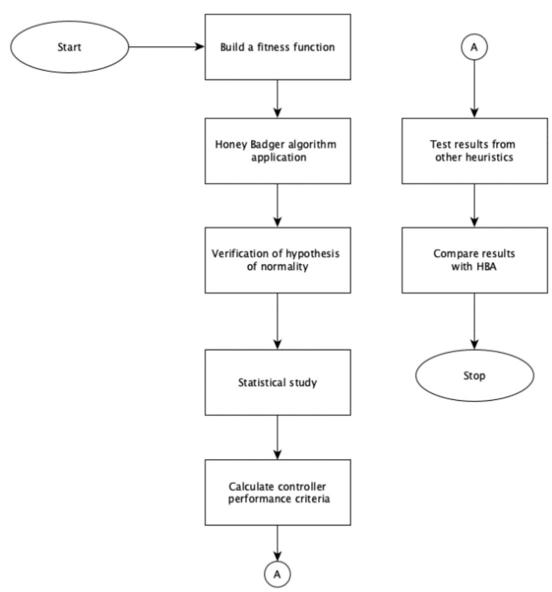

Fig. 5 Methodological scheme

For the application of the HBA, a scheme of univariate experiments is proposed as shown in table 2, which consists of keeping a $C\ \ as$ constant of equation 4 and varying the parameter β.

Table 2 Experiments proposed

Test	Value of β
1	$\beta = 1$
2	$\beta = 2$
3	$\beta = 3$
4	$\beta = 4$
5	$\beta = 5$
6	$\beta = 6$

Each of the tests indicated in table 2 is executed 40 times, this determined with the central limit theorem, which indicates that for populations of infinite size with 40 samples it is possible to determine their statistical behavior. To later determine the type of test that will explain if there are significant differences between the experiments. After determining the best PID obtainable with the HBA, the performance criteria described in Table 1 are compared with the results of the CHIO, since it is one of the recently developed heuristics.

4. RESULTS

Table 3 shows the result of the normality test, in this case the Shapairo test was applied to check the assumption of normality.

Table 3 Result of the normality test

Test	Value of significance p	Compliance with the assumption of normality
1	0.1925	Meets Assumption
2	0.05992	Meets Assumption
3	0.2911	Meets Assumption
4	0.0321	No meets Assumption
5	0.04197	No meets Assumption
6	0.5237	Meets Assumption

When verifying that 4 experiments meet the assumption of normality, an Anova test is carried out on them in order to determine if there are significant differences between samples, as a result a significance value of 0.953 is obtained, showing that there are no statistically significant differences. In addition, Figure 6 shows a box diagram where the behavior of the 40 tests on each of the tests can be observed.

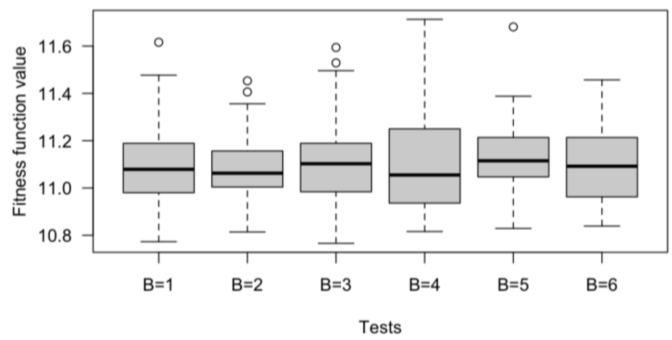

Fig. 6 Boxplot of experiment

The results for experiment 6 are presented since it represents the default value, suggested by the specialized literature, in table 4 a statistical summary of the results of the fitness function and the values of the PID regulator is shown.

Table 4 Statistical summary

	Fitness	k_p	k_i	k_d
min	10.84	-3.0043	-2.9989	-1.3422
1st Quartil	10.96	-2.9528	-2.2643	-0.4231
mean	11.09	-2.7093	-1.6966	-0.3365
3rd Quartil	11.21	-2.8005	-1.3710	-0.1567
max	11.46	-0.2253	-0.3357	-2.127

Figure 7 shows the response to the step of the phenomenon to be controlled, while Table 5 shows the results to the performance criteria on the plant.

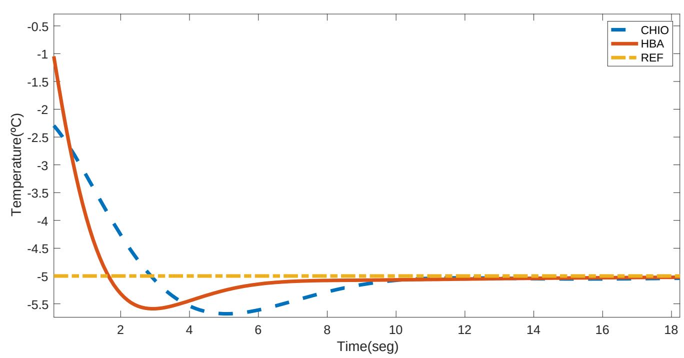

Fig. 7 Response to the step of the PID controller

The performance indices of the controller are shown in Table 5. It shows that all indices show a decrease with respect to that obtained by the CHIO algorithm.

Table 5 Performance indices of the controller

	ITAE	IAE	ITSE	ISE
CHIO	26.962	7.1998	13.397	8.7653
HBA	15.332	5.1699	5.2961	7.9423

Figure 8 shows the convergence of the algorithm, i.e. the number of iterations required to reach an optimal value

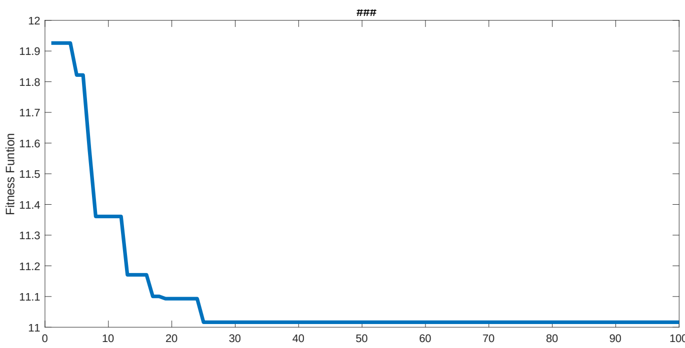

Fig. 8 Convergence of the algorithm

5. CONCLUSIONS

An interesting alternative to the problem of fitting the values of a PID controller is found in evolutionary algorithms, which are methods that are in constant development, although the HBA algorithm is a new heuristic, it is necessary to submit it to studies that complement the one presented in this proposal, first of all it is necessary to carry out a multivariate study, changing values in the parameter β and the value C of given that the concept used in the literature is by default but is not explained in a forceful way.

Regarding the application of the HBA with respect to the CHIO, it shows an acceptable response that in the first instance satisfies the problem of reducing the performance criteria raised. It is necessary in the future to try other control techniques and optimization problems, both numerical and combinatorial.

The use of HBA, based on what is proposed in this research, allows us to theorize in the approach of a line of research focused on the tuning of intelligent controllers, modern or classical, not only in the field of cooling of space devices, but also in the design of energy converters or in the study of investment portfolios. In terms of combinatorial problems, such as the rural postman or the assignment of schedules, it would be possible to think of some possible operation based on the coding of the initial population of the algorithm.

It is important to note that the object of study of the documented proposal was to determine if it was feasible to use an HBA as a tuner for regulators, which is proven in the results section. Now, having determined its feasibility, it is possible to propose as future work the comparison of this technique against two classic algorithms: The genetic algorithm and a swarm of particles.

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