# Dual stage cascade controller for temperature control in greenhouse

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**ABSTRACT**

In this paper, a dual stage cascade controller PI-(1+PD) is adopted to maintain and control temperature in greenhouse environment based on a smart and intelligent gorilla troops optimization (GTO) method for evaluating the controller gains to enhance the system response by reducing the error value and minimize the integral time absolute error (ITAE) fitness functions during simulation. The simulation results are obtained by using MATLAB 2019, then compared with two conventional controllers proportional integral derivative (PI and PID) based on evaluation parameters for all controllers in term of peak time, rise time, settling time and overshoot to show its efficient response if compared with other controllers used.



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## 1. INTRODUCTION

A greenhouse is an environment used for promotes all the matters that enhancing the agriculture efficiency level. It is generally consisting of four components internal air, soil, plant and finally covers of the surface. Surface isolates the external environment from internal environment. It saves the internal plants from the external bad climate and diseases. It can be consisting of polyethylene of glass. The inside air is the more essential components or aspects of the greenhouse. The temperature level within the greenhouse mainly affects to the physiological processes of the plants, thus, it is essential keep it in an acceptable value based on the crop difference and the geographical place of the system environment. This improves its growth and raises the production quality with reducing energy consumption [1].

Regulating the greenhouse climate needs various kinds of systems to obtain a particular effect on the internal climatic parameters. The main effects are ventilation and heating, but nowadays greenhouses can adopt new systems like carbon dioxide injection systems or artificial lights [2]. Different studies in automatic control for regulating the internal temperature of a greenhouse was adopted; it was presented different control techniques, in terms of precise control, proportional integral derivative (PID) controller are commonly used due to its simple structure, operation and robustness [3]. Various methods are adopted like neural networks and PID controllers have been suggested, the radial basis function (RBF)-PID controller, PID gains tuning and adopting the initial weight values of the neural network are used to generates the values of parameter tuning [4], [5]. A smart control technique depending on ZigBee was adopted. In that paper, JN5139 was proposed as a control part, the sensor data arrangement was smoothed three times, and the data are used to realize the real-time collection of greenhouse environmental matters values [4]. Some studies controlling the temperature using PID [5], [6], neural network control method [7], [8], hybrid control system [9], and fuzzy logic technique [10], [11].

In this paper a dual stage cascade controller is proposed for controlling the temperature in greenhouses based on intelligent gorilla troops optimizer (GTO) tuning algorithm for finding all the controller gains used for give a stable behavior with best desired value and remove any noise may appear in the system response during simulating time. This paper is arranged as follows: section 2 demonstrates the greenhouse modeling. Section 3 describes the controller suggested. Section 4, explains the GTO algorithm, section 5 shows the simulation results obtained and finally section 6 explains the conclusions part of this paper.

## 2. MODELING OF THE GREENHOUSE TEMPERATURE CONTROL SYSTEM

Designing and modeling the greenhouse plant has a significant issue on the systems efficiency and performance improvement the most realistic model for implementing the proposed controller is the autoregressive model with exogenous input (ARX) [12], whose parameters can be easily obtained using an identification processes. Figure 1 shows representation of an ARX model for a single-input/output (SISO) system [2].

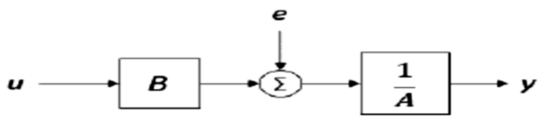


Figure 1. An (ARX) model representation

The climate control problem was addressed using a multi-input single-output (MISO) technique to simulate the greenhouse production process for simulation purposes. The benefit of the provided control structure is to modify the greenhouse's internal temperature y(t) (see Figure 2). A MISO system [13], [14] can be used to model the evolution of this quantity.

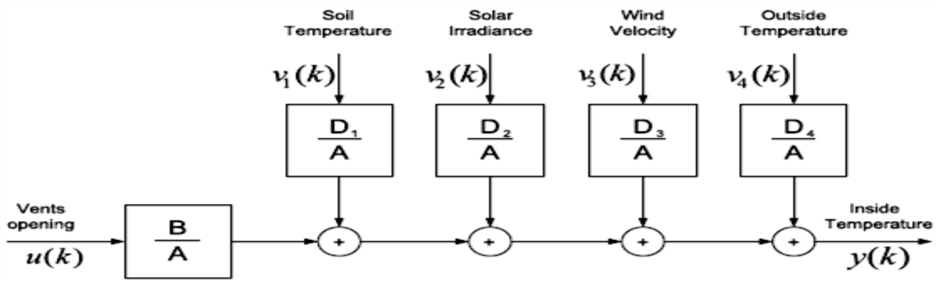


Figure 2. Diurnal temperature control using a greenhouse modeling approach with disruptions

Therefore, the suggested model can be characterized in discrete-time form by this (1):

$$A(z).\,y(t) = \sum_{i=1}^{nu} B_i(z).\,u_i\,(t - nk_i) + e^{(t)} \qquad (1)$$

where the inputs are $u_i$, y is the output, $nu$ is the overall number of inputs, e is the white noise and $nk_i$ is the samples number that is matching to the time delay of every input. A(z) and Bi(z) are parameters with the structure shown in:

$$A(z) = 1 + \ a_1 \cdot z^{-1} + \cdots + a_{na} \cdot z^{-na} \qquad (2)$$

$$B_i(z) = b_{0_i} + \ b_{1_i} \cdot z^{-1} + \cdots + b_{nb_i} \cdot z^{-nb_i} \qquad (3)$$

The order of polynomials A and B are denoted by na and nb, respectively, and a and b represent the variables that are computed in the process's identification step using real data.

After obtaining the high-order ARX model, a model reduction stage is completed for process control, as previously mentioned. The relationship between each input and output was represented as a first-order definition given by a transfer function defined in the Laplace domain for continuous time in this model reduction stage, as (4) [15]:

$$G_i(s) = \frac{Y(s)}{U_i(s)} = \frac{k_i}{\tau_i s+1} e^{(-L_i s)} \quad (4)$$

where static gain denotes ki, ti denotes the time constant, and Li denotes the time delay or (dead time), all of which are applied to the ith input. To obtain the values of the parameters appeared in (4), an open-loop response of the system was estimated based on [16] and it is show in (5) and (6):

$$G_i(s) = \frac{Y(s)}{U_i(s)} = \frac{6.51}{111.52s+1} e^{(-10.5\, s)} \quad (5)$$

$$G_i(s) = \frac{Y(s)}{U_i(s)} = \frac{0.0056}{s^2+0.1s+8.45\times10^{-4}} \quad (6)$$

## 3. THE PROPOSED CONTROLLER

PID controllers are classified as an easy and traditional controllers adopted for improving the performance of the system. Nowadays, many studies suggested different modifications and structures for more enhancement in system response either by combining PID controller with some intelligent methods such as neural network [17] or using fuzzy logic with it [18] or modify its structures based on system behavior as in [19], [20] or adopt the fractional analysis either the integral or the differential parts of PID controller or together by fraction number for improving system response, this form of enchantment is a special case controller and become an improved structure of conventional PID controller [21]. In this paper, a novel cascade structure named proportional-integral-one plus integral-derivative PI-(1+ID) [22] is suggested to control temperature based o GTO algorithm and its block diagram is shown in Figure 3.

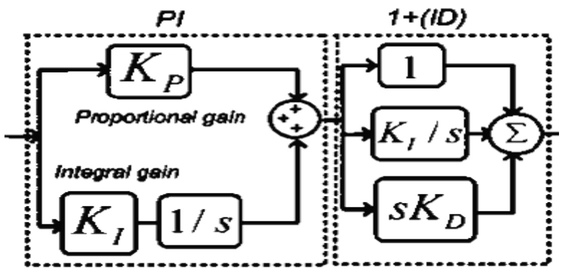


Figure 3. Cascade PI-(1+ID) controller [22]

## 4. GORILLA TROOPS OPTIMIZATION

Optimization methods being an efficient way to solve different problems, because in nature, natural organisms have a collective intelligence which is translated to excellent algorithms one of these methods is called artificial GTO. They live in troops, different adult females with their offspring with one adult male have silver colored hair called silverback gorilla. Each male and female want to leave their group to a new group, male gorillas try to leave their groups and go to comprise a new ones by drawing females attention in the new group while other males stay in the same place which were born in and live in the silverback group. If the adult leader dies, these gorillas that stayed will either dominate or deal with the silverback to control it. In this method, the adult leader is regarded as the optimal solution, then the other males gorillas follow him and go away from the weakest one (worst one), two phases will translate this behavior as show in [23], [24]:

### 4.1. Exploration phase

In this phase, each gorilla is regarded as a competitor for the optimal solution chosen by the silverback one. Three choices appeared in this phase and translated in (7), first one is to increase the GTO exploration by migrating to unknown place while the second is to balance between the two phases exploitation and exploration by migrating to other group and finally third choice is for increasing GTO ability for searching in different places by migrating to identified place.

$$GX(t+1) = \begin{cases} (UL - LL)\, r_1 + LL, & if\ rand < P \\ (r_2 - a)X_r(t) + L \times H, & if\ rand \geq 0.5 \\ X(i) - L(L(X(t) - GX_r(t)) + r_3\,(X(t) - GX_r(t))), & if\ rand < 0.5 \end{cases} \tag{7}$$

The current location is the vector $(t)$, "$GX(t+1)$" is candidate position in the next iteration. The variable $X_r(t)$ is used for any member of the group candidates who are randomly chosen from the group and $GX_r(t)$ is the place of this random gorilla. $UL$ and $LL$ are the upper and lower bands of the parameters, and the parameters $r_1$, $r_2$ and $r_3$ are random values between 0 to 1. The parameters$a$, $L$ and $H$ can be evaluated as indicated:

$$a = C \times (1 - It\ /\ MaxIt) \tag{8}$$

$$C = \cos(2 \times r_4) + 1, \tag{9}$$

$$L = c \times l \tag{10}$$

$$H = Z \times X(t) \tag{11}$$

$$Z = [-a\, , a], \tag{12}$$

### 4.2. Exploitation phase

In this phase two choices are there, the first one follows the adult leader silverback and the second is will compete for adult females, each choice is obtained by comparing the calculated value of a parameter in (12), if a≥W, the first choice is selected, but if a<W, and the second choice is taken. W is a variable set before start the algorithm.

#### 4.2.1. Following the adult silverback gorilla

In this choice the leader is the silverback gorilla, all other gorillas obey his plans to find food sources, it is selected if $a \geq w$ and translated as indicated:

$$GX(t+1) = L \times M \times (X(t) - X_{silverback}) + X(t) \tag{13}$$

$X_{silverback}$ is the silverback leader's location, and $X(t)$ is the gorilla location; the parameters $L$ and $M$ are selected.

#### 4.2.2. Competition for adult females

This choice is selected when the young gorilla males reach the age puberty, competition are violent because they fighting with other males for create their groups by choosing adult females. This choice is selected if $a < w$ and it can be translated as shown in (14)-(17):

$$GX(i) = X_{silverback} - (X_{silverback} \times R - X(t) \times R) \times A \tag{14}$$

$$R = 2 \times r_5 - 1 \tag{15}$$

$$A = \beta \times E \tag{16}$$

$$E = \begin{cases} N_1 = rand \geq 0.5 \\ N_2 = rand < 0.5 \end{cases} \tag{17}$$

where "R" translates the impact force, which are calculated using (9), $r_5$ is random value [0,1] When conflict occurs, (12) is used for calculate the violence level in conflicts and A is the coefficient vector that is used for measuring the violence value and it is represented by (10). Some variables are predetermined before starting the process like a, $\beta$, $E$ are used as an influence of violence on the decision dimensions. Finally, the cost of all GX (t) is calculated, if the cost of GX(t)<X(t), the GX(t) will adopt as the X(t) decision and the optimal choice selected among the whole group is selected as a silverback leader. Figure 4 translate all GTO algorithm steps. The fitness functiom used witn this algorithm to monitor the error value and reduce it each iteration ITAE function [25].

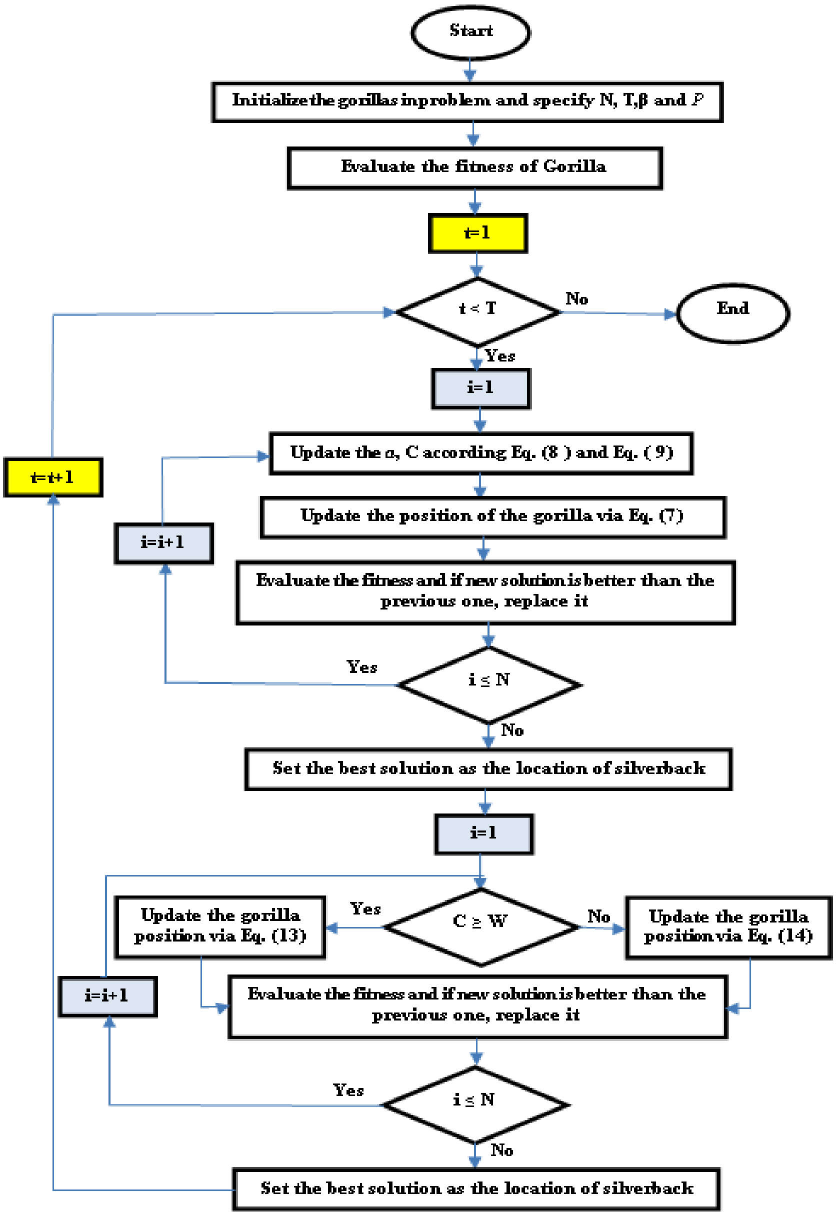


Figure 4. GTO algorithm flowchart

## 5. SIMULATION RESULTS

To start simulation for controlling temperature in greenhouse we must specify the desired temperature needed, in this study 25 °C is regarded as an optimal value for the greenhouse environment and based on this the controller with the smart GTO optimization method will track the and monitoring the response to reach to the desired value with a stable behavior, all simulation results is obtained using MATLAB 2019 and the parameter of the GTO algorithm is shown in Table 1. The system error between desired and actual response is monitored and minimized using ITAE function [26], [27] as shown in (18) in the smart GTO algorithm iterations, Figure 5 indicated block diagram of proposed system.

$$ITAE = \int_0^{\infty} t|e|\, dt \tag{18}$$

Table 1. GTO parameter

| Description | Value |
|---|---|
| No. of population | 50 |
| Maximum number of iterations | 30 |
| Dimension | 4 |

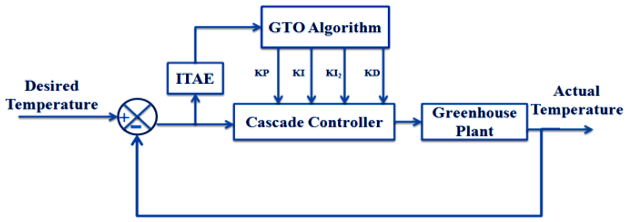


Figure 5. Cascade controller of greenhouse system based on GTO algorithm

The system response is indicated in Figure 6 and for demonstrate the controller efficiency a comparison with two conventional controller (PI and PID) is done and the response of all controllers is shown in Figure 7, and all controllers gain values is shown in Table 2. The response analysis results for the comparison of all controllers are shown in Table 3. Based on evaluation parameters of the controllers in Table 3, it can be shown that the efficient behavior of the suggested cascade controller is appeared clearly in comparison with other classical controllers (PI and PID), it's tracking the desired response faster and with stable behavior, it is faster than PI controller by 7 sec. while faster than PID with 62.5 sec, and if compared these results with [4] it can be seen that PID controller is slower but when combined with fuzzy logic give best results and reach to stable response at 30 sec and in [8] also PID controller and the neural radial basis function used, suffer from high overshoot and slower response while in combine them together RBF-PID it will be more stable and fast response with settling time equal to 9.01 s. This superiority in its response is due to the novel dual stage cascade controller and also due to the benefits of the smart GTO optimization method which is reflected on its transient analysis (Mp, tp, tr, and ts) and led to a stable and efficient performance.

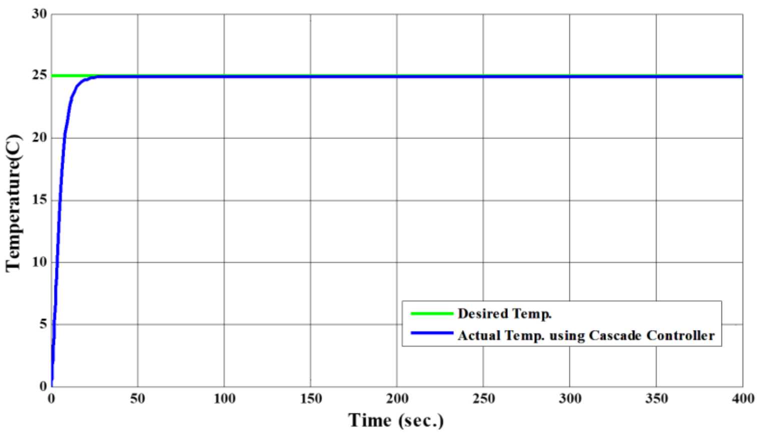


Figure 6. Response of greenhouse systems based on optimal cascade controller

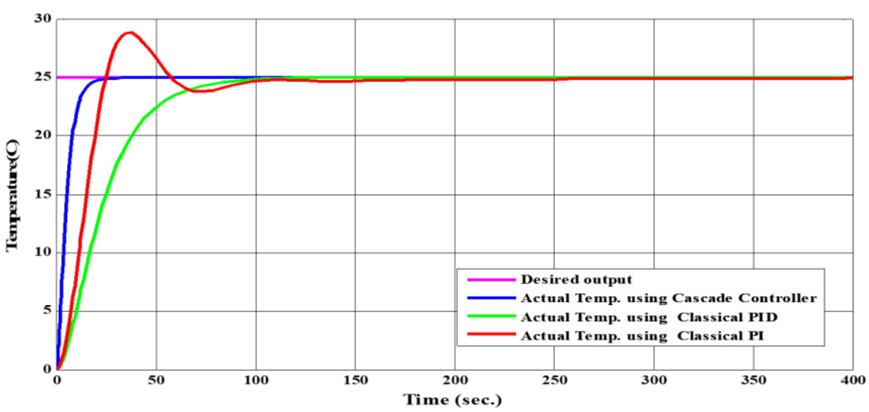


Figure 7. Response of greenhouse systems based on different controllers

Table 2. Tuned gains of all controllers

| Controller | $K_p$ | $K_{I1}$ | $K_{I2}$ | $K_D$ |
|---|---|---|---|---|
| PI | 1.66 | 0.011 | - | - |
| PID | 1.234 | 0.006 | | 14.33 |
| Cascade Controller | 24.135 | 0.0312 | 0.0009 | 4.58 |

Table 3. Response analysis results for the three controllers

| Controller | Maximum overshoot (Mp %) | Peak time (tp) | Rise time (tr) | Settling time (ts) |
|---|---|---|---|---|
| PI | 16.72 | 37 | 17 | 24.5 |
| PID | 0 | 150 | 44.5 | 80 |
| Cascade controller | 0 | 25 | 9.5 | 17.5 |

## 6. CONCLUSION

In this paper, a novel cascade controller is suggested to control the temperature in greenhouse environment with the benefits of a smart variables tuning method based on GTO algorithm to reach to the desired temperature. For test controller efficiency a comparison with other two classical types of controllers in terms of settling time, rising time, peak time, and overshoot. The simulation results showed that the cascade controller is superior in its behavior in without any noise or fluctuation while classical PI suffer from high noticeable overshoot (16.72), the second classical PID controller does not have an overshoot but it suffers from delay in its response to reach to the desired value with settling time 80 sec.

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