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Optimizing Indoor Temperature Control Using Genetic Algorithm for PID Tuning

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ABSTRACT

This study was conducted to explore ways to save energy focusing on Temperature control through genetic algorithm (GA)based on the Proportional Integral Derivation controller (PID) to obtain the best PID gain parameters (kp, ki, kd) through which the settling time, steady state error, and overshoot are improved, which showed better performance than using traditional PID because of its fast and sharp control it provided. The best results for the parameters were using integrated time absolute error (ITAE)as a GA objective function where k [0.8598 0.0669 0]. However, by using Integrated of absolute error(IAE), the best results obtained were k [12.9765 0.2534 0], It is possible to improve system's response from using traditional PID which is considered a long time (more than 25 seconds) as compared to the PID with Genetic algorithm(GA) .

The study showed that the best results were obtained using the IAE as an objective function for GA, as the system reached the stable state in the shortest possible time.

Introduction

Cooling systems may be the most commonly device used at this time in buildings by converting electrical energy to mechanical energy for cooling purposes. Temperature is an effective parameter, and controlling it contributes to creating a comfortable environment for workers, for example, increasing the comfort of employee productivity, improving sleep quality, which leads to better relaxation. If the temperature is not controlled quickly and sharply, we can catch a cold or flu when it decreases significantly or fatigue and dehydration if the temperature rises significantly. As for industries, controlling the temperature helps maintain computers and other electronics, which increases their lifespan and reduces maintenance costs. Preserving materials in the food and pharmaceutical industries [1]. There are many methods used to improve and control temperatures. Many researchers have used multiple methods, including Cohen Coons (CC), Ziegler Nicholes (ZN), Particle Swarm Optimisation (PSO), Nelder Mead (NM), and Genetic Algorithm (GA). Research has found that the best way to control temperatures is to use a Genetic Algorithm (GA). Through which the best gain parameters are obtained to achieve rapid stability and improve response. In this research, GA based PID will be used to control the room temperature at 25 degrees Celsius to provide comfort for those persons. PID is used to control most industries due to its ease of handling [2]. There are traditional methods for controlling the PID, such as (CC) and (ZN) [3]. Intelligent control is the best because of the non-linear properties of the systems, which make control complex due to changing parameters over time. Recently, intelligent methods have been used to control nonlinear systems, and these methods include genetic theory, artificial neural networks (ANN), and fuzzy logic (FL) to solve these complex problems [4]. The control process using the traditional PID requires a long time and the experience of operators to adjust the parameters [5]. Genetic theory is an optimisation process for conventional PID controller parameters [3, 5, 6]. In this study, (PID with GA) used to control the interior temperature of the building by improving the PID (three gain parameters) to reduce the error and stability time and increase accuracy. Integrator Time of Absolute Error (ITAE) and Integrator of absolute Error (IAE) were used as objective functions for (GA) to find out which is better in obtaining stability in less time to reduce the energy consumption and cost in building. There are many ways to minimise energy usage and cost in building. One of these ways is to apply passive building strategies [7]. Also, predicting the building's energy consumption had an important role in determining the required energy.]8[

Jian Wei Li ,etc. (2011) [1], created a temperature control system. They used logic to tune the settings of a PID controller, which then managed temperature fluctuations. This method helped address issues typically seen in PID controllers, like stabilisation and excessive. Overshooting leads to better control performance.

A. Jayachitra and R. Vinodha (2014) [2], introduced a technique to enhance PID parameters for a tank reactor by utilising various objective functions; Integral of square error (ISE), (IAE) and (ITAE). The main goal of the biochemical sectors was to optimise PID controller parameters aiding in the control of processes with nonlinear characteristics. The research focused on optimizing PID parameters to overcome the limitations of a linear PID controller ensuring the operation of the tank reactor process throughout its operational spectrum. Simulation findings demonstrated that the "GA - PID" controller tuned perfectly with fixed parameters exhibited performance in terms of set point tracking and disturbance handling .

Wang Chunchen and team (2017) [5], created a model for analysing gas mixtures through modelling techniques. They introduced a Genetic Algorithm (GA) with selection, adaptive crossover, and mutation probabilities. MATLAB simulations were carried out to confirm the efficiency of GA PID control. The results showed that GA PID outperforms PID controllers, by offering accuracy and quicker settling times.

Reem Al Hadeethi and Wisam Hacham (2023) [8] study, delved into analysing the energy usage patterns within the lecture hall located at the University of Baghdad (UOB) in Iraq at (AKCOE). They collected weather data and detailed information about the building's construction over a timeframe, which was then organised into a dataset. This dataset was utilised to estimate the energy consumption of the building through the application of intelligence techniques and data analysis methods. The research utilised the Scikit learn Python library to implement machine learning algorithms focusing on using the Multi-layer Perceptron regressor (MLP Regressor) algorithm for predicting consumption.

The accuracy of these predictions heavily relies on having training data, for AI processes to achieve precision. Validation of prediction accuracy was conducted using root mean square error (RMSE) .

Dawei Hu ,etc. in (2023) [9] studied how to control the temperature of a heating furnace by using algorithms to create a fuzzy PID system. They utilised the MATLAB fuzzy control toolbox to set up the reasoning system and establish the rule table. Additionally, they used the Simulink platform to build simulation models for both PID and fuzzy PID systems aiming to understand how different parameters affect the system. By conducting simulations in MATLAB/Simulink, they compared PID with fuzzy PID algorithms to study temperature control, in heating furnaces and analyse how each parameter impacts system performance. Their results indicate that implementing a PID control approach reduces overshoot enhances response times and improves temperature regulation.

Basim Al Najari ,etc. in (2023) [10] utilised a PID controller to manage pH levels during the neutralisation process, which exhibited erratic pH behavior. Their method involved analysing the pH loops transfer function using MATLAB's system identification toolbox creating and applying a PID controller refining its performance through the particle swarm optimisation (PSO) algorithm and comparing it with tuning techniques like Ziegler Nichols (ZN) and MATLAB tuner methods.

This this study leads to the implementation of a PID controller with a genetic algorithm (using MATLAB) to regulate the building's internal temperature. This system targets a comfortable temperature of 25°C as quickly as possible, minimising both energy consumption and operation time.

1. The proposed temperature control systems

1.1 The PID control system

It is a smooth and powerful control method [11] and is the most widely used in industries [12]. It consists of (Kp, Ki, Kd) three gain parameters, as in Fig. 1.

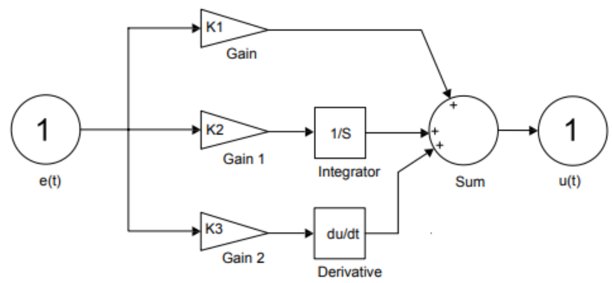

Fig. 1. PID controller structure.

The PID units' input is e(t) and the output is u(t) as in Eq.1 [13].

$$u(t) = k_p . e(t) + k_i . \int e(t) + k_d . de(t)/dt \qquad (1)$$

It can be programmed by many programs for example Python, Arduino, and MATLAB and their simulations. Here MATLAB and its simulation were used.

1.2 The GA based PID control system Space

GA is a computing method inspired by the process of natural selection, which is used to solve search and optimisation problems through iterative evolutionary optimization processes [14].

By discovering the appropriate objective functions to solve this function to obtain the optimal solution after starting randomly and finding the optimal solution for this function from a set of possible solutions. The algorithm applies its operations to create a new population and the process continues until it meets the stopping criterion. By using MATLAB the parameters of GA were found.

Here's a breakdown of the steps involved:

1. Problem Definition:

Objective: Minimise the difference between the desired temperature (setpoint) and the actual temperature (error).

2. Chromosome Representation:

Encode each set of PID gains (Kp, Ki, Kd) into a single chromosome.

3. Initial Population:

Generate a random population of chromosomes representing different sets of PID gains.

4. Fitness Evaluation:
Simulate the temperature control system for each chromosome (set of PID gains). Calculate a fitness score based on the system's performance. Common metrics include: (ISE), (IAE), (ITAE).

5. Selection:
Choose a subset of chromosomes with high fitness scores (better temperature control) for reproduction.

6. Crossover:
Apply crossover operators to exchange genetic information between selected parent chromosomes.

7. Mutation:
Introduce random changes to individual genes (gain values) in some chromosomes with a low mutation rate. Mutation helps maintain diversity and explore new areas of the search space to avoid getting stuck in local optima.

8. Iteration and Selection:
Repeat steps 4-7 for a predefined number of generations. In each generation, the new population replaces the old one, carrying the best genetic information for improved temperature control.

9. Selecting the Best PID Gains:
Choose the chromosome with the highest fitness score (best temperature control performance) from all generations. Decode this chromosome to obtain the optimal PID gains (Kp, Ki, Kd) for the system. The goal is to maintain the graph at 25°C with the lowest possible error, the fastest response, and the least overshoot by using a cooling device and a PID controller.

The chromosomes represent a set of PID parameter values.

The genetic theory begins with an initial guess, randomly generating chromosomes that may or may not be the best.

It then simulates the control system using cooling controlled by the PID.

Using the IAE or ITAE function, the absolute error is calculated.

At this stage, the parents for the next stage are selected according to the principle of survival of the fittest.

Gene exchange occurs to generate new chromosomes, generating random mutations to discover better solutions that were not apparent in the previous mutation.

This process is repeated from steps 4 to 7 until all old elements are replaced and continuous improvement is achieved.

The best PID parameters are then selected from among all tested generations. This is all done using special programming in MATLAB.

1.3 The mechanical ventilation system

The temperature control system for a cooling system usually consists of a set of components such as a fan or cooling pump that helps in distributing air or cooling liquid, sensors such as temperature sensors to measure the temperature, in addition to a controller that controls the cooling process based on Data provided by sensors and signals received from the central unit. The temperature at which the sensor senses and produces a voltage, and negative feedback. As for the input, it is known as the setpoint temperature.

The difference between input and measured temperature results in an error voltage that enters the control to adjust it and regulate the power entering the cooling system. The mathematical model of the cooling system is represented as in Eq. 2, Eq. 3 [15] and the sensor transfer function as in Eq.4 [16].

$$Q = M.C.s.T(s) + (\dot{m}.C_p + \frac{kA}{x})\,T(s) \qquad (2).$$

$$C_p = a + b.T + c.T^2 + d.T^3 \qquad (3).$$

and the sensor transfer function (T.F.) is

$$\frac{T_{sen}}{T} = \frac{1}{\frac{m_{sen}.C_{sen}}{h_{conv}.A_{sen}}.s+1} \qquad (4).$$

Where

(Q): cooling load (heat removed by cooling system) in (kW)
(T): return air temperature in (^{0}C)
(M): thermal mass (kg)
(C): specific heat capacity ($kJ\,.\,kg^{-1}\,.\,K^{-1}$)
(k): thermal conductivity coefficient ($\frac{W}{m.C}$)
(A): indoor surface area (m^2)
(X): outdoor wall thickness (m)
($\dot{m}$): exchanging air flow rate (kg/s)

(C_p): air specific heat capacity ($kJ . kg^{-1} . K^{-1}$)
(a,b,c,d): coefficients for air gas (unitless).
(T_{sen}): measuring temperature (^0C)
(C_{sen}): sensor heat capacity($kJ . kg^{-1} . K^{-1}$)
(m_{sen}): sensor mass
(A_{sen}): sensor area
(h_{conv}): convection heat transfer coefficient ($\frac{W}{m^2.C}$).

Fig.2 displays control of cooling system temperature using PID only.

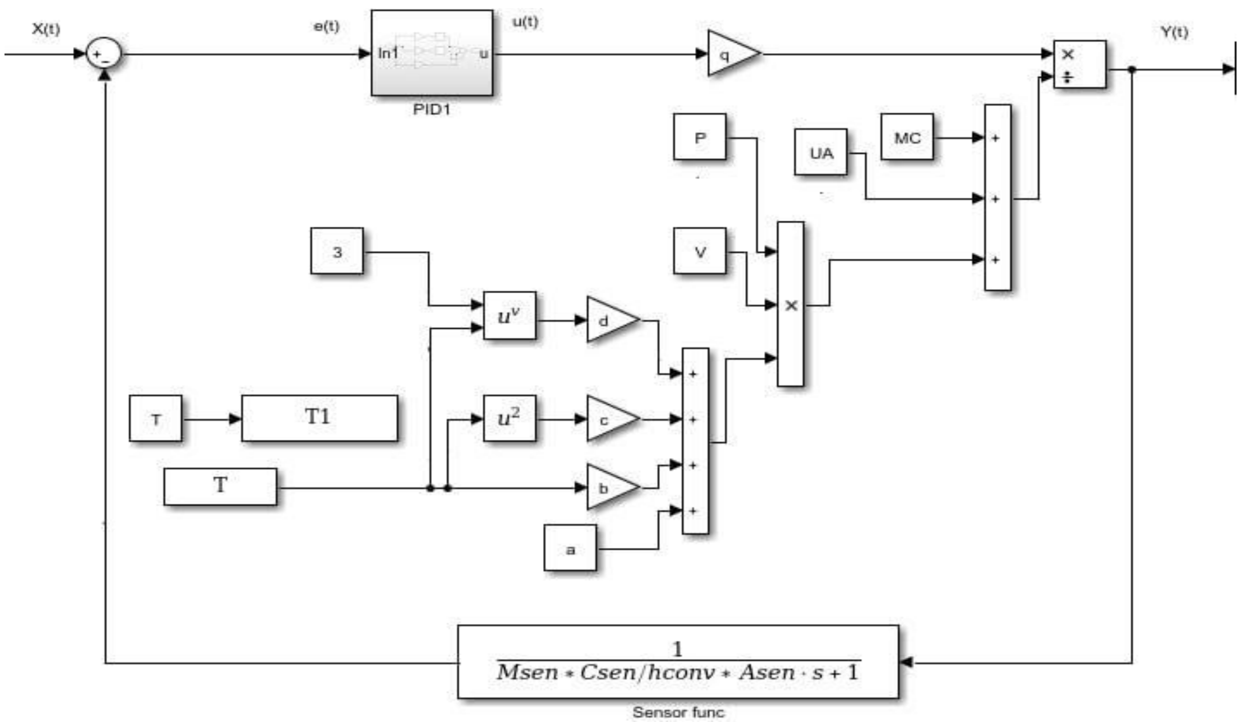

Fig. 2. Control of indoor temperature of the selected building by using PID only.

GA-based PID controller is proposed method to control on indoor temperature of buildings. After making a random selection of the PID controller parameters. The objective function was chosen to work with genetic theory, so the GA searches for the best values for this objective function. Here IAE & ITAE were used as objective functions for GA to perform the optimisation. Which uses the error as follows:

$$IAE = \int |e(t)|. dt \quad (5).$$

$$ITAE = \int |e(t)|. t . dt \quad (6).$$

Then apply the genetic theory, and there is no specific rule for choosing the size of the population, so the selection is made randomly according to the theory of trial and error, so that the algorithm appears in the best form.

The MATLAB program was used to create a simulation of GA-based PID. It was observed after several conditions, such as using the PID only as in Fig.2, or combining it with the genetic theory, using the objective function IAE once and ITAE again.

As in Figs. 3 and 4 using different objective functions (IAE, ITAE) respectively.

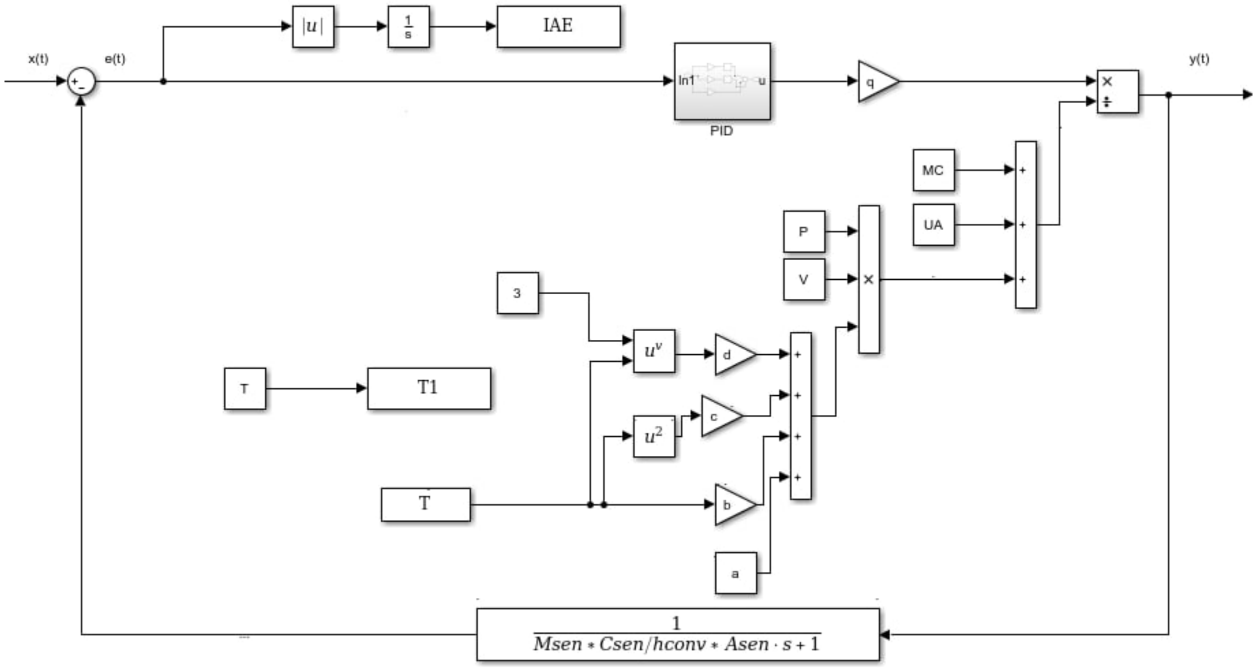

Fig. 3. control on indoor temperature of selected building by using PID with GA (IAE objective function).

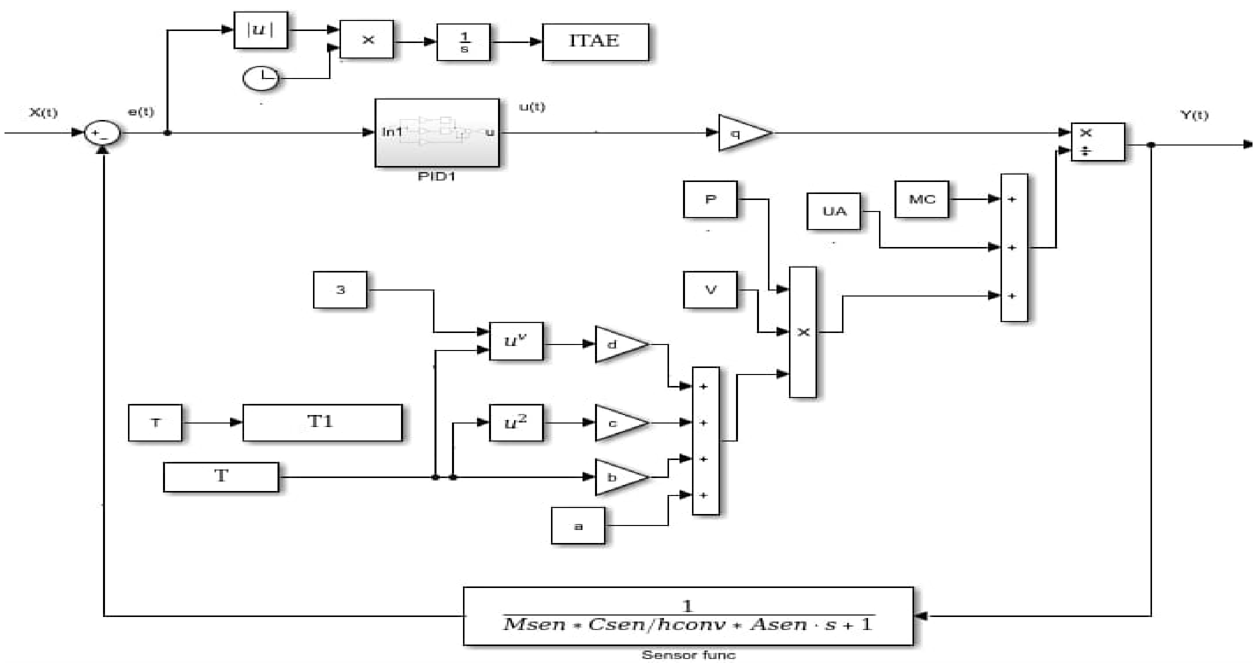

Fig. 4. control on indoor temperature of selected building by using PID with GA (IAE objective function).

The PID block here represented as in Fig.1 y(t) is the output temperature, x(t) input temperature ,and e(t) is the error (difference between input x(t) and measured temperature y(t). The PID controls this error to reduce it, while the GA, using the objective function, can tune the PID. Here the indoor temperature must be 25 Celsius by controlling the speed and quantity of incoming air through a mechanical ventilation system such as a fan.

The type of (supply only) was used here: It is a system that allows fresh air to enter from the outside through a fan and is distributed into the rooms through a duct, which increases indoor air quality [17]. As for the internal polluted air, it exits as a result of internal pressure through door and window openings as shown in Fig.5 [18].

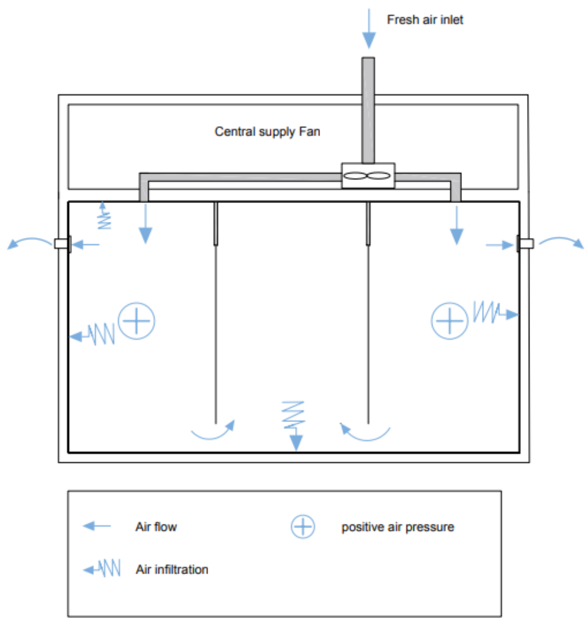

Fig. 5. Mechanical ventilation used (type Supply ventilation system).

1.4 Sensor type selected for sensing air temperature

Environmental sensor, (E2) type air temperature sensor, made by the company Tripp. Lite, under the E2MT unit of EATON in America (EATON's Energy Management Technology),is renowned for its measurement capabilities guaranteeing trustworthy data. It functions efficiently in temperature conditions making it versatile for use. Moreover, it can be seamlessly incorporated into network and remote control setups allowing for temperature monitoring, from afar. It is used to measure the temperature range in a room to make controlling on indoor temperature easy and perfect [19]. It measures the temperature as system feedback to compare it with the setpoint temperature to produce the error that the PID improves. It can be placed on the interior wall of the room or inside the interior of the split device. The best place to put it is on the internal wall far from windows. Fig.6 displays the temperature sensor shape (E2) [20].

Fig.6.A. The outer shape of the E2 indoor temperature sensor is used

Fig.6.B. The internal content of the E2 indoor temperature sensor is used.

Result

Using MATLAB program, the cooling temperature in the building is controlled using GA (with ITAE/IAE objective function) based PID to controlling on indoor temperature. Fig.7 displays the response of the cooling system that is tune by GA (ITAE objective function) with PID. It arrives to the best result quickly at gain values [kp , ki , kd]equal to [0.8598 0.0669 0] respectively .

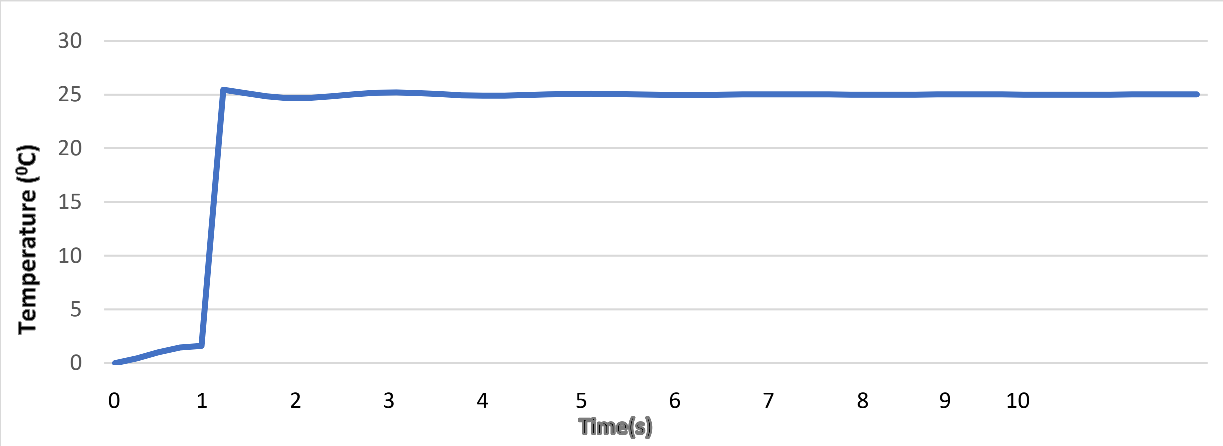

Fig. 7. Cooling system response using GA (ITAE) with PID by MATLAB simulation. It arrives at the best result quickly with gain values [kp, ki, kd]equal to [0.8598 0.0669 0] respectively , it takes about four seconds only to settle at 25 Celsius.

When using GA (IAE objective function) based PID, it is noted that its response consume more time to arrive to the stability as shown in Fig.8 at gain values equal to [12.9765 0.2534 0], but when using traditional PID only, it's difficult to stabilize it in the simulation time used, it is pass 25 seconds without stability, as in Fig.9

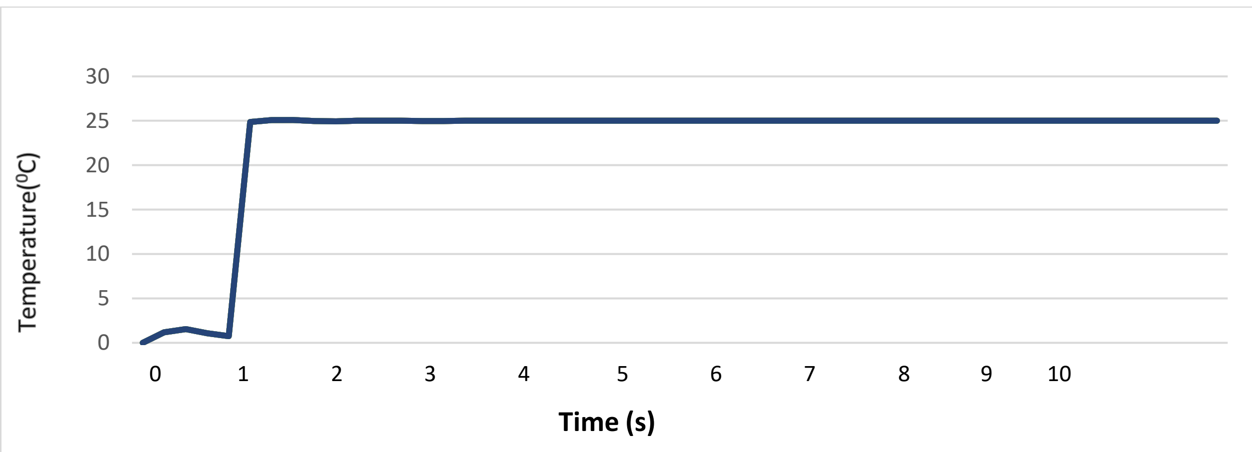

Fig.8. Cooling system response using GA (IAE) with PID by MATLAB simulation. It arrives at the best result quickly with gain values [kp, ki, kd]equal to [12.9765 0.2534 0]respectively, and it takes about two seconds only to settle at 25 Celsius.

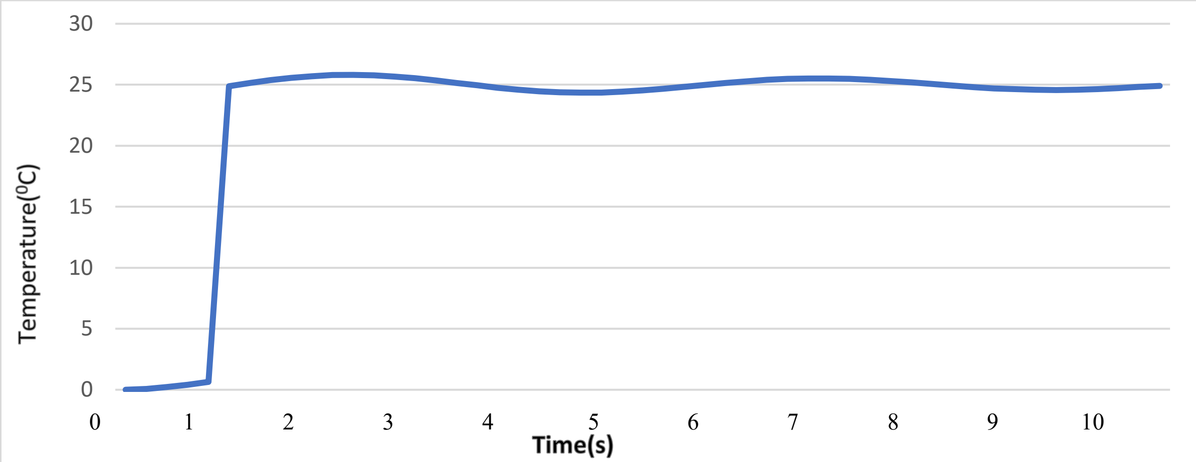

Fig. 9. Cooling system response using traditional PID by MATLAB simulation. It takes more than twenty-five seconds to settle at 25 Celsius.

When using IAE as the objective function in a GA-PID system for room temperature control instead of ITAE, reaching stability may be faster for several reasons related to the way both functions work:

Time Weight in ITAE: In the ITAE function, the error is multiplied by time, making errors that occur later have a greater impact on the outcome. This can lead to more gradual improvements in the system over time, sometimes resulting in a slower response to reach stability. In contrast, IAE does not have this time weight, meaning that errors are taken equally seriously regardless of their timing. This may lead to faster response in systems that don't require long-term error reduction as in ITAE.

Balancing speed and accuracy: When using IAE as an objective function, the goal is to reduce errors regardless of time, leading to faster system response. This can help reach steady-state conditions more quickly than ITAE, which focuses on more precise long-term error reduction.

System Response Behaviour: Since IAE doesn't place as much importance on errors occurring later (as in ITAE), the algorithm moves faster to balance error control and achieve stability sooner.

Therefore, it can be argued that IAE can contribute to faster stabilisation because it focuses on reducing errors as early as possible without significantly impacting errors occurring later, making the system more likely to respond to changes and achieve stability.

The three figures above show that the IAE is the best for thermal systems, as it can be used in systems that require high overall accuracy over long ranges. This applies to all thermal systems that reach stability in the shortest time when using IAE, unlike kinetic systems such as drones, aircraft, and others that reach the fastest stability using ITAE.

The Discussion

The goal of this study is to improve building performance and achieve energy consumption levels that mirror real-world scenarios by controlling its temperature using (GA with PID) to control the internal temperature by improving gain parameters to reach stability quickly which reduces energy consumption. T is controlled by the indoor unit through the circulating air driven by the cross-flow fan. Through the heat exchange process, the heat is absorbed from the indoor space, low temperature T, and rejected to the outdoor space, high temperature T_{amb}. The heat exchange process between the indoor and outdoor units. For the cooling system, the internal energy is the summation of mass (M, kg), specific heat capacity (C, kJ·kg−1·K−1), and temperature (T, °C). The mass and specific heat capacity of the cooling system are assumed as constants. Where the air density = 1.22 kg/m³, the air velocity = 2551.5 m³/h, the thermal mass = 75 kg, a, b, c, and d, the air C_p coefficients are:

(28.94*10^{-3}, 0.4147*10^{-5}, 0.3191*10^{-3} & -1.965*10^{-12}) respectively, Thickness equal to 35 cm, U value 3.416 W/m^2.^{0}K. When using GA (IAE objective function) based PID, it is noted that its response consume more time to arrive to the stability at gain values equal to [12.9765 0.2534 0], the IAE is the best for thermal systems, it can be used in systems that require high overall accuracy over long ranges. This applies to all thermal systems that reach stability in the shortest time when using IAE, unlike kinetic systems such as drones, aircraft, and others that reach the fastest stability using ITAE.

Conclusion and Recommendations

The use of genetic algorithms, which will be the potential application and future work, can contribute to enriching these results in terms of controlling the temperature of the spaces that were studied, after using traditional PID, GA-PID with IAE as objective function and finally using GA-PID with ITAE as objective function for GA, the result clear that:

1- The PID parameters gain reachs to the best value quickly when using GA-PID with IAE to achieve stability in the HVAC system at K [12.9765 0.2534 0].
2- Experimental Validation: Implementing the GA-tuned PID controllers with optimised gains as mentioned above on a real-world HVAC Al-Khwarizmi Engineering collage to validate the simulation results under actual operating conditions and assess their robustness against real disturbances (e.g., door openings, external temperature fluctuations).
3- Comparative Analysis with Advanced Control Strategies: Extending the comparison to include other advanced optimisation algorithms (e.g., Particle Swarm Optimisation – PSO)
4- Multi-Objective Optimisation: Investigating the use of multi-objective genetic algorithms to simultaneously optimise not only control performance (e.g., minimum IAE/ITAE) but also energy consumption, by incorporating energy efficiency metrics directly into the fitness function.
5-Integration with Building Management Systems (BMS): Exploring the practical challenges and benefits of integrating the proposed GA-PID tuning methodology within existing or future Building Management Systems to enable adaptive and autonomous optimisation of HVAC operations in smart buildings

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