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ENHANCING TEMPERATURE CONTROL METHOD OF THERMAL VACUUM CHAMBER FOR SATELLITE TESTING USING OPTIMIZATION ALGORITHM: A REVIEW

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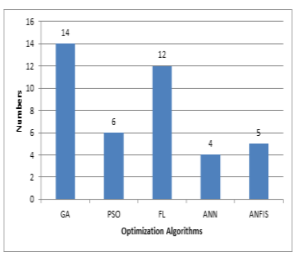
Graphical abstract



Abstract

This paper studies a comparison of optimization algorithms to enhance temperature control method of thermal vacuum chamber (TVC) for satellite testing. The gaseous nitrogen (GN2) is used in TVC to control the temperature requirement and proportional integral derivative (PID) controller is adopted in order to realize it. However, the temperature profile is fluctuated and more time is needed before it managed to achieve the temperature set point. Therefore, a study is done to identify the algorithms that can be applied to optimize the temperature control system of TVC. The study is aim to improve the current temperature control in terms of settling time and overshoot. The method used in the review is by comparing the optimization algorithms that have been used to optimize the temperature control system. The study will be done using other related works that had been done by other researchers. From the review that has been done, the genetic algorithm (GA) is believed to be the best method that can be implemented into the temperature control system of TVC. In the future, the study will further analyse by using simulation tools and real time data generated by the TVC.

Keywords: Thermal vacuum chamber; temperature control; PID; optimization algorithm

1.0 INTRODUCTION

A thermal vacuum test is one of the most critical satellite environmental tests. The test is used to determine flight-worthiness and to detect workmanship deficiencies of a satellite by subjecting the satellite to flight-like operating conditions. The entire tests can be run in a thermal vacuum chamber (TVC). TVC is used to simulate the harsh cycle of extreme temperature (hot and cold) in vacuum condition as experienced by the satellite. During the operation, the temperature inside the TVC will be controlled by the Gaseous Nitrogen (GN2) and proportional integral derivative (PID) controllers that are equipped in the temperature control system inside the TVC. Although several groups of PID controller are used to achieve a good performance of the TVC, the temperature profile is still fluctuated and more time is needed in order to stabilize the temperature set point. Numerous literatures had already claimed that the implementation of PID controller is often burdened with problems such as time delay and PID tuning problem [1][2][3][4][5]. Therefore, this is one of the reasons why temperature profile in TVC system is fluctuated and more time needed before it is able to stabilize.

Due to that, the optimization algorithms will be study to see whether these algorithms can be apply into the system and thus enhance the temperature control method of TVC for satellite testing. This study will be discussed and finally, the conclusion will be given.

2.0 OPTIMIZATION ALGORITHMS USED FOR TEMPERATURE CONTROL L

This section elaborates the previous work done for temperature control system from various applications. The mechanism to control the temperature has been discussed and the researchers have developed ideas and tools to make it more efficient and robust by using different optimization algorithms. There are a range of optimization algorithms such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Fuzzy Logic (FL), Artificial Neural Network (ANN), Adaptive Neural Fuzzy Inference System (ANFIS), and so on.

GA is known as the optimization algorithm that is widely used in optimizing temperature control systems followed by other algorithms [6]. GA has been used to solve errors in nonlinear functions of PID controllers and it is proved that GA is able to solve the problem and provide better performance of the temperature control system [7][8][9]. The researchers also discovered that GA is suitable in solving the parameter issue in PID controller [4][6][10]. By improving the PID parameter, GA is able to provide a short settling time and improve overshoot in the temperature control system. Besides that, the steady state error also can achieve ± 0.0001°C by using GA [11]. In terms of costing, GA helps to minimize the costs and energy consumption by optimizing the temperature control system [12][13]. GA also proved to solve large time delay of the temperature control system [14]. Table 1 summarizes all the related works that is done using GA.

Table 1 Summary of related works Using Genetic Algorithm (GA)

No.	Problem	Performance	Tools
1.	To tune the control parameters and minimize error [4]	It is more efficient and robust. It is also able to tune the controller fast and reduce error.	Matlab
2.	Less cost and time constraints [6]	Optimize machining process parameters	NA
3.	To improve the timing parameters [7]	Improve the timing parameters.	Matlab
4.	Error on nonlinear functions of PID [8]	Lower exceeds, short settling time and better performance.	Matlab
5.	Temperature control [9]	Minimized overall absolute error and reduce design efforts.	Matlab
6.	Unstable if the PID parameters are improperly tuned [10]	Overshoot improved 86.42%, while the average improvement on settling time is greater than 50%.	Matlab
7.	To optimize PID controller [11]	Steady state error is ± 0.0001°C	Matlab
8.	To optimize the temperature regulation system for residential buildings [12]	Minimizes costs and energy by helping users shift their energy consumption to off-peak times.	Matlab
	PID controller tuning [13]	Improve settling time and more stable.	Matlab
9.	Large inertia, large time delay and time varying [14]	Able to optimize filter parameters	NA
10.	Hard to meet the real-time control requirement [15]	The steam temperature stabilizes very fast	Matlab
11.	Nonlinear and need for robustness process [16]	Improve the performance of the process and robust	Matlab
12.	PID controller tuning [17]	Achieved set point tracking and disturbance rejection with optimized parameter.	NA
13.	PID controller tuning [18]	Improve settling time	Matlab

PSO is able to improves the control performance and achieved good result for large delay and variable object [19][20]. The PSO is proven to be more efficient as it is able to tune the control parameters of PID very fast and reduce the error [4]. Besides that, PSO also optimizes nonlinear and unstable systems [13]. Table 2 summarizes all the related works that is done using PSO.

Table 2 Summary of related works Using Particle Swarm Optimization (PSO)

No.	Problem	Performance	Tools
1.	To tune the control parameters and minimize error [4]	It is more efficient and robust. It is able to tune the controller fast and reduce error.	Matlab
2.	Tuning of PID controller parameter [13]	Optimize non-linear and unstable systems	Matlab
3.	Parameter Estimation of a PID controller [18]	Improve the performance	NA
4.	Large time delay, time-varying, big interference [19]	It improves the control performance and achieved good control effect for large delay.	NA
5.	Large time delay and time varying [20]	Improve the step response	Matlab
6.	To set the desired temperature [21]	Reach temperature stability less than ±1°C.	Matlab
7.	Tuning of PID controller parameter [22]	Obtain higher quality solution with better computation efficiency	Matlab

Fuzzy Logic (FL) is also proven to reduce response time in PID controllers [23] and solve the time delay issue [2][3][24][25]. Besides that, the FL can perform self-tuning for PID parameters and reduce overshoot [5][26]. The FL is also able to provide a robust system and good tracking performance [27][28]. In terms of stability, FL is proven to be stable in both linear and nonlinear plants [29]. It is believed that FL is easy to programme [30]. However, another researcher claimed that FL rules are difficult to be generated [2]. Table 3 summarizes all the related works that is done using FL.

Table 3 Summary of related works Using Fuzzy Logic (FL)

No.	Problem	Performance	Tools
1.	Time delay [2]	Better performance than traditional cascade PID control scheme.	NA
2.	Time delay [3]	Small overshoot, short settling time and shorter rising time.	Matlab
3.	To tune the PID parameters [5]	Improve process rise time, process settling time, percent overshoot and steady state error.	Matlab
4.	To improve the timing parameters [7]	Improve the timing parameters.	Matlab
5.	Time varying and delay in control process [23]	Reduce response time, and no steady state error.	Matlab
6.	Time delay and unstable system [24]	More robust	NA
7.	Large time constant, long time delay and high order [25]	It improves the steady state much faster with a small error.	Matlab
8.	Difficult to obtain good effect in control of the temperature [26]	Fuzzy self-tuning PID control rapidly increased by 10%, the overshoot is reduced to 30% and has higher speed and stability.	Matlab
9.	To stabilize and reduce the number of parameters used [27]	Robustness and good tracking performance	Matlab
10.	To meet stringent temperature-control requirements [28]	The temperature fluctuation of the system is less than ±7 ◦C, strong robustness and excellent adaptability.	NA
11.	To have a stable system [29]	It improved the stability both for the linear or nonlinear plant.	NA
12.	To control the liquid's temperature in the water bath [30]	It is easily programmed and achieve more accurate result and saves the energy of the water bath system.	Matlab

Artificial Neural Network (ANN) has also proven to solve the time delay issue [19]. ANNs are adaptive systems that can be trained and tuned PID parameters but its input data that generalized to acquired knowledge is difficult to extract and understand [33]. Table 4 summarizes all the related works that is done using ANN.

Table 4 Summary of related works using Artificial Neural Network (ANN)

No.	Problem	Result	Tools
1.	To improve the reliability, security and control precision of the system [16]	Fast response speed, high precision and wide range of temperature control.	Matlab
2.	Large time delay, time-varying, big interference [19]	It improves the control performance and achieved good control effect for large delay and variable object.	NA
3.	To minimize the rate of water loss during storage by optimal temperature [34]	It minimizes the rate of water loss and maintains the temperature at the lowest level.	NA
4.	The temperature is not easy to detect and monitor [35].	The operations of the production are optimized, and are improved.	Matlab

Adaptive Neural Fuzzy Inference System (ANFIS) solved the fuzzy function and rules [2]. It is proven that ANFIS can improve the PID controller [36] and is better than ANN [33]. Besides that, ANFIS is also able to improve response time and reduce settling time [37]. Table 5 summarizes all the related works that is done using ANFIS.

Table 5 Summary of related works using Adaptive Neural Fuzzy Inference System (ANFIS)

No.	Problem	Result	Tools
1.	To control water temperature [33].	15% better than PID and 5% better than ANN	PID Controller
2.	To avoid the overshoot and absolute error [36]	No overshoot than the conventional PID Controller.	Matlab
3.	To reduce the running costs and improve site operations [37]	The transient response was improved and the settling time has been reduced.	Matlab
4.	To generate and adjust the membership function and fuzzy rules [38]	It solves problem regarding membership function and its parameters	Matlab

Other optimization algorithms such as Differential Evolution Algorithm (DEA), Firefly Algorithm (FA), Internal Model Control (IMC), Model Predictive Control (MPC) and Model Reference Adaptive Control (MRAC) had also been used to improve the temperature control system but the usage of these algorithms are limited because other algorithms that have been discussed previously proved to better. Figure 1 shows the number of researches in temperature control system using various optimization algorithms.

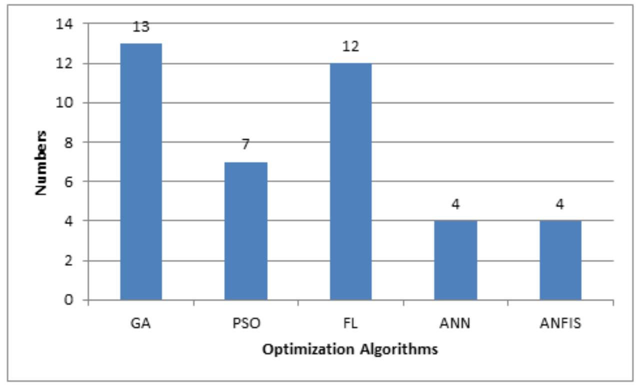


Figure 1 Numbers of researches in temperature control system using various optimization algorithms

According to the review conducted, each of these algorithms has certain functions that can produce a robust system. There are also algorithms that help in terms of time saving and reducing error for better data accuracy. In this study, the optimization algorithm that is mostly been used in temperature control system is GA. However, in terms of PID parameters tuning, GA, FL and PSO have been popularly used. Therefore, in order to identify which algorithm is the best, these algorithms will be further analysed and discussed.

3.0 COMPARISON ANALYSIS

In this study, only one optimization algorithm will be chosen to be implemented into the TVC temperature control system. Therefore, the strength and weakness of each algorithm is identified in order to ensure that the algorithm is the most suitable one to be implemented into the system. There are a few criteria that have been specified in order to improve temperature control in the TVC which is improving process settling time and overshoot. Other criteria that are also considered include stability and robustness. These criteria will be used to identify the best algorithm that can be implemented into the temperature control system of the TVC. Table 6 describe the criteria and analysis results of the comparison. These criteria will be used to identify the best algorithm that can be implemented into the temperature control system of TVC.

Table 6 Criteria and analysis results

Criteria	Description	Optimization Algorithms		
		GA	FL	PSO
Settling Time (Seconds)	Time required for the process variable to settle	9.3936s [13]	2175s [5]	11.505s [13]
Overshoot (%)	Percent amount of the process variable overshooting the final value	28.7017% [13]	0.6456 % [5]	44.821% [13]
Stability	System stabilisation, ±1°C	±0.0001 °C [11]	Less than ±7 °C [22]	Less than ±1°C [30]
Robustness	Tolerance to disturbances and nonlinearities	Yes [4]	Yes [5]	Yes [4]

From the comparison study that has been done, GA is better than FL and PSO in terms of settling time. Meanwhile, for overshoot, FL is better than GA and PSO. However, by using the same parameters, GA overshoots and settles very quickly compared to FL [31]. In terms of stability, GA proved to be better than FL and PSO. Lastly, all algorithms are proven to be robust based on previous work that had been done. Therefore, GA is found to be the best algorithm that can be implemented into the temperature control system of the TVC. With that, GA will be further investigate and analyse to see whether it is suitable to be implemented into the system.

4.0 ENHANCING TEMPERATURE CONTROL METHOD OF TVC FOR SATELLITE TESTING

The proposed system in enhancing the temperature control of TVC for satellite testing is shown in Figure 2. The goal is to produce optimum PID controller to control temperature set point required for the TVC. PID controller design is done offline using the model generating process of TVC temperature control system. Design optimization problems in PID controller as previously stated, where the fitness function, *f* is the settling time and overshoot. In order to find a solution, the GA is used. The *f* value is calculated based on the characteristics of the TVC process model response.

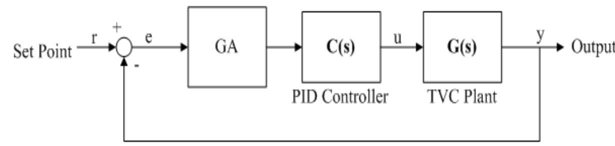


Figure 2 GA-PID for temperature control system of TVC

5.0 CONCLUSION

As a conclusion, the GA will be used to enhance temperature control method of TVC for satellite testing. This is because GA was found to be the most widely used and capable of tuning the PID parameters. Besides that, it is able to improve the settling time and overshoot problem compared to other methods. In addition, GA also proved to be stable and robust for temperature control system. However, this result is based on the implementation that was done in ambient condition. None of it is done for the vacuum application. Therefore, in the future work, GA will be study for vacuum application which is TVC together with the real time temperature data that has been generated using PID controller in TVC. A simulation will be done using Matlab Simulink and the new configuration of temperature control system of TVC will be evaluated.

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