

Design of Heating Furnace Temperature Optimization using Hybrid ANFIS-PSO

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Abstract -- Intelligent control design for industrial heating furnace temperature control is indispensable. PID, Fuzzy, and ANFIS controllers have been proven reliable and have been widely used. However, the constraint is how to choose the best controller gain. This paper proposes an approach to determine the most appropriate controller gain value using the artificial intelligence tuning method. It is a combination of the Adaptive Neuro Fuzzy Inference System (ANFIS) and Particle Swarm Optimization (PSO) methods. Several methods are used as comparison, namely Conventional PID (PID-Konv), Matlab Autotuning PID (PID-Auto), PSO tuned PID (PID-PSO), and Hybrid ANFIS-PSO. The results show that the proposed ANFIS-PSO controller is the best choice to control this nonlinear process, being compared to conventional single-loop control system, conventional PID, and Matlab-2013a Autotuning methods. The proposed ANFIS-PSO design method performs the best with an overshoot of 0.0722, undershoot 0.0085, and the settling time at 18.8789 seconds, which can produce a fast response with strong dynamic performance.

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Intelligent control
Particle Swarm Optimization
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I. INTRODUCTION

The rapid development of technology requires the fulfillment of high need of automation-based industry. A reliable control system is required to ensure the system reliability and to increase the efficiency. The control of heating process in a furnace system is an example of important automation in an industry. Process control needs to be considered to result in products with high added value. The tuning of process control parameters must be ensured to make the system performance meeting the operating objectives. Optimization is needed to produce good temperature control results, as it offers more stable and efficient results than conventional controls. Artificial Intelligence-based intelligent control has been developing a lot to improve conventional controls, PID control, Fuzzy control, Adaptive Neuro Fuzzy Inference System (ANFIS) [1], and other types of controllers. Many intelligence methods have been used in system optimization, where each method has its own advantages and disadvantages. Many researchers have studied, developed, and implemented artificial intelligence methods to solve their system optimization problems, for example in vehicle steering control[2], photovoltaic tracking control[3][4], micro hydro frequency control [5], etc. This paper aims at designing a temperature model for a heating furnace using a control being tuned using Artificial Intelligence (AI) and the Particle Swarm Optimization (PSO) method. It is purposed to make the control of heating furnace temperature more stable and efficient [6].

II. METHODS

A. Furnace Temperature Control System

Furnace, as seen in Fig. 1, is a device used to increase the temperature of an object using burning fuel. The function of the furnace is to generate heat energy and to result in combustion. The fuel used can be liquid fuel and gaseous fuel, which are mixed by the burner to produce combustion. The burner is a device that supplies or regulates the fuel and air to be burned. This device works by using a balanced composition of gas and air mixed. One of its uses is to mix air and fuel to create good combustion and

increase combustion efficiency [7]. In general, the burner section is divided into two parts, namely the pilot burner and the main burner. The pilot burner is used as the starting point for the ignition process, then after ignition it will continue with the main burner until it has a state where the burner consumes more gas and air [8]. Heating is produced by distributing the fuel through tubes or pipes that are arranged as well as possible in the furnace. Heat transfer occurs in three ways, namely convection, conduction, and radiation [5].



Figure 1 Furnace for the Combustion Process

The furnace temperature control system considered in this paper is shown in Fig.2. T_1C represents the primary controller, T_2C represents the secondary controller, T_1T is for the set of material temperature measurement points, whereas T_2T is for the furnace temperature measurement.

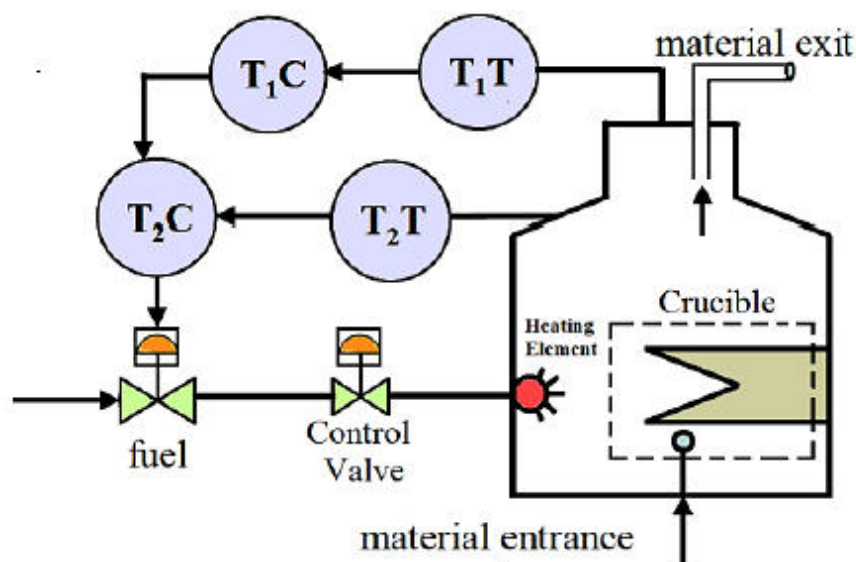


Figure 2. Furnace Temperature System [9]

The output of the main controller (T_1C) becomes the set points to the second controller (T_2C). T_2C is used to control the fuel flow. In the heating process, the material is placed in a container to be heated to a certain temperature. There are three components to control in the combustion chamber, from fuel control to raw material export control. These components are furnace, fireplace, and heated raw materials.

B. Control System Modeling

To represent the schema of heating furnace temperature system shown in Fig.2, the transfer function

equations given in (1) and (2) are to be used in simulation using MATLAB Simulink software.

$$G_1(s) = \frac{1/90}{(s+1/30)(s+1/3)} \quad (1)$$

$$G_2(s) = \frac{1/10}{(s+1/10)(s+1)} \quad (2)$$

One controller that is still considered reliable in the control model is the PID controller. The controller has been widely used and proven to be able to optimize a control system properly and precisely. The reason for using PID controller is that it is a simple control tool, easy design, stable, and gives a fast response. However, in its use, there is often an offset or difference in the value of the set point with the value of the result variable, and there are still quite large oscillations or wavy responses [10].

Controlling the value of the PID constant is required to eliminate the offset properly. If not controlled, it can result in a large deviation value with a very long response time compared to conventional methods. Derivative control also needs to be done so that the control rate can be controlled because it can reduce or eliminate excessive oscillations. The offset that occurs is usually caused by too large integral control.

C. Particle Swarm Optimization (PSO)

Particle Swarm Optimization (PSO) is one of the artificial intelligence methods that is often used for control system optimization. PSO is a population-based algorithm by exploiting individuals in the search for destination results. PSO is based on the social behavior of a flock of birds or fish in a group. The social behavior of swarm consists of the individual actions of birds or fish and their effects in a group of birds or fish [11]. In PSO, the population is called the swarm and the individual is called the particle. Each particle moves with a certain speed which is adapted from the search area (P-Best). Among several search results saved are to be chosen the best position globally (G-best) ever achieved.

A distinctive feature of PSO is the heuristic and probabilistic adjustment of the particle velocity. If a particle has a constant velocity, the result at the position of some of the particles will form a straight line. An external disturbance (external factor) can deflect the line and the path will move the particle through the search space. From the results, it is expected that the particle can accelerate, approach, and finally reach the most optimal point, which is called the P-Best. The extrinsic factor is the best location the particle has ever visited. The best position of all particles is called the Global Best (G-Best)[12].

D. Adaptive Neuro Fuzzy Inference System (ANFIS)

The Adaptive Neuro Fuzzy Inference System (ANFIS) is a method that combines the working principles of an Artificial Neural Network (ANN) with a Fuzzy Inference System (FIS)[13]. By combining ANFIS with ANN, it is expected to minimize the weaknesses of each method. Both methods still use machine learning principles. FIS, which requires the involvement of experts in compiling rules, is no longer needed in ANFIS. ANFIS itself is not only capable of processing numerical numbers, but also language-based knowledge (linguistics). In addition, ANFIS is more transparent to users than ANN which is like a black box. This is because the results of the ANFIS rule can be known by the user. However, most research shows that ANN is more accurate than ANFIS[14]. Between the two types of FIS (Mamdani and Sugeno), the ANFIS Sugeno is more recommended because the process is faster. ANFIS structure can be seen in Fig.3 whereas the FIS flow is shown in Fig.4.

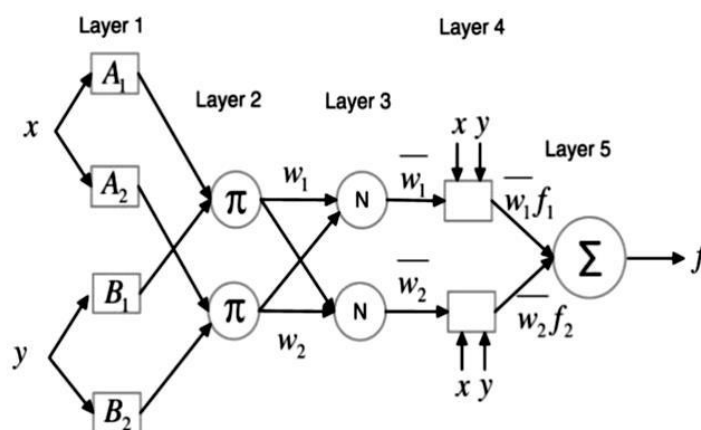


Figure 3. ANFIS structure

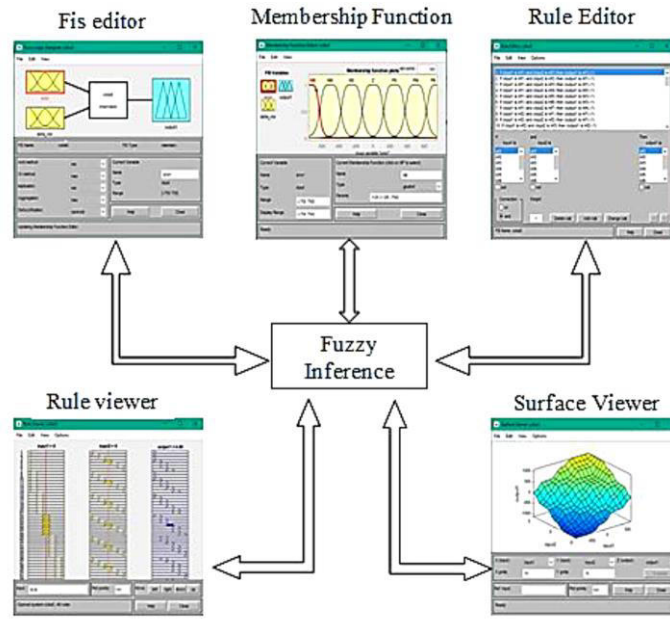


Figure 4. The FIS flow

III. RESULTS AND ANALYSIS

A. Controller Design

The design of several temperature settings on the heating furnace is given in Fig.5, with the switch is in position 1.

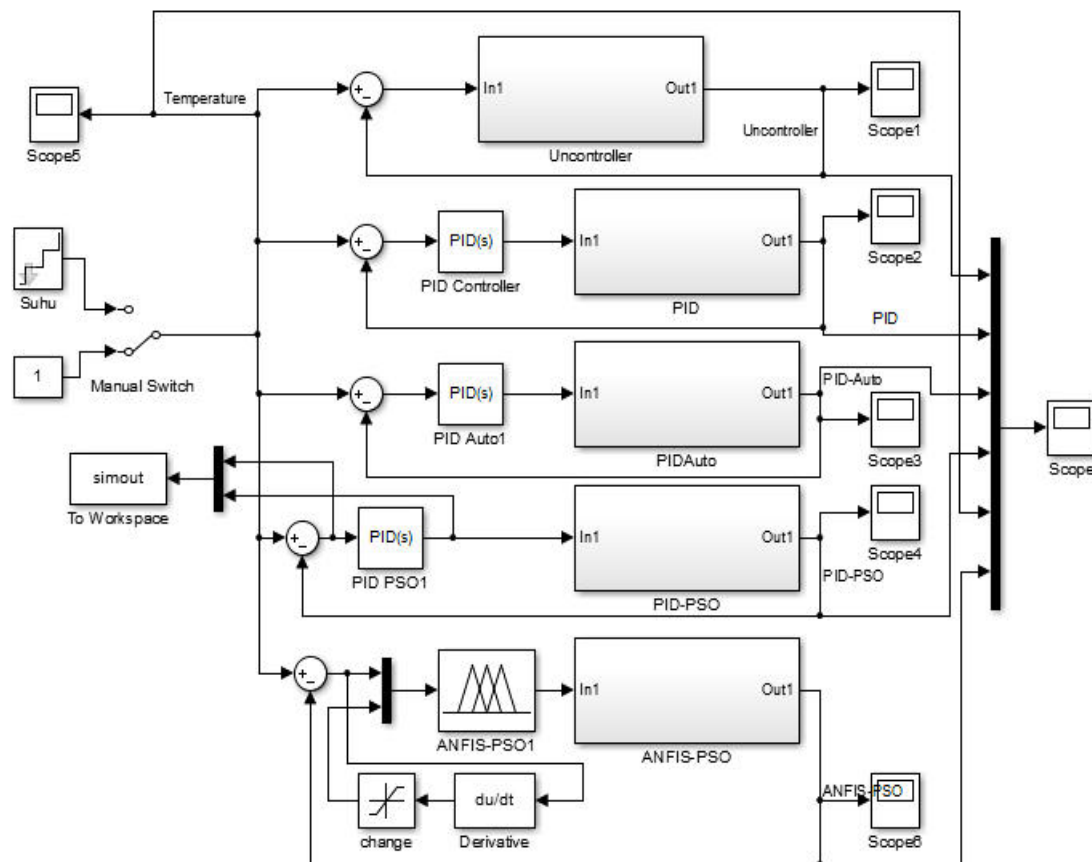


Figure 5. Design of several temperature settings on the heating furnace

The data results of the ANFIS training can be seen in Figure 6.

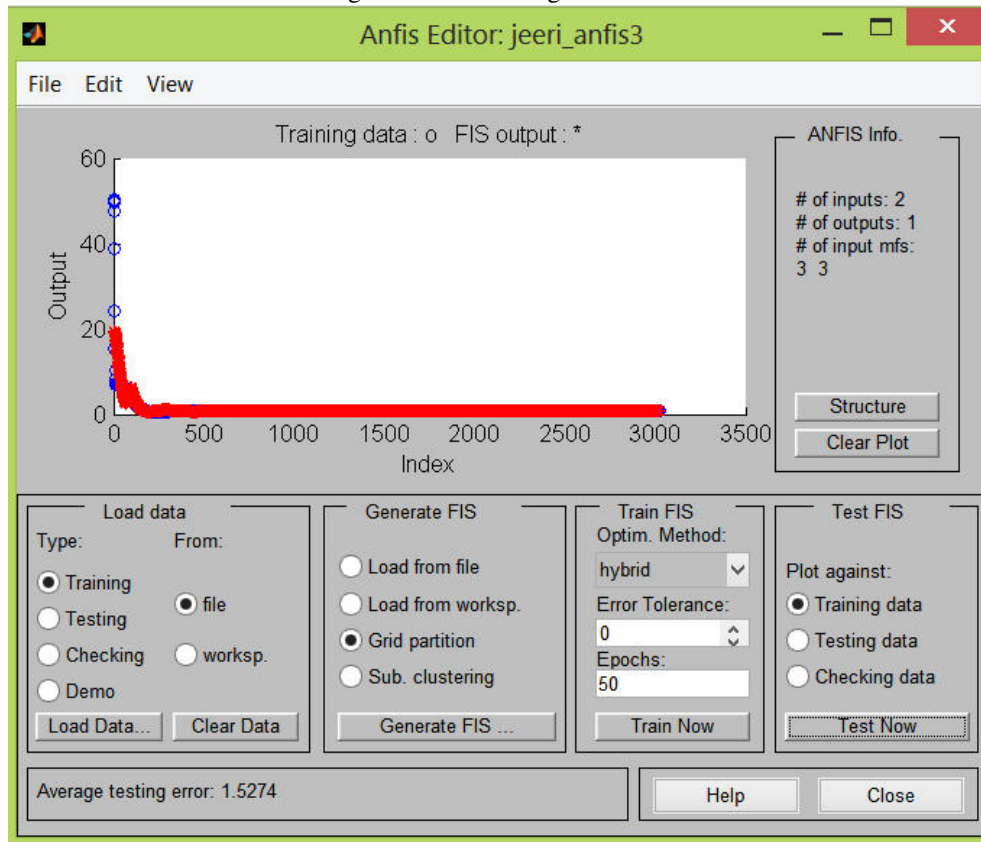


Figure 6. The resulted data of the ANFIS training

B. Simulink Response Results

The simulation results of the proposed Hybrid ANFIS-PSO method are to be compared with several other methods, namely Conventional PID (PID-Konv), Matlab Autotuning PID (PID-Auto), and PSO tuned PID (PID-PSO). The comparison results for all transient responses of dynamic performance characteristics were calculated and tabulated as shown in Fig.7.

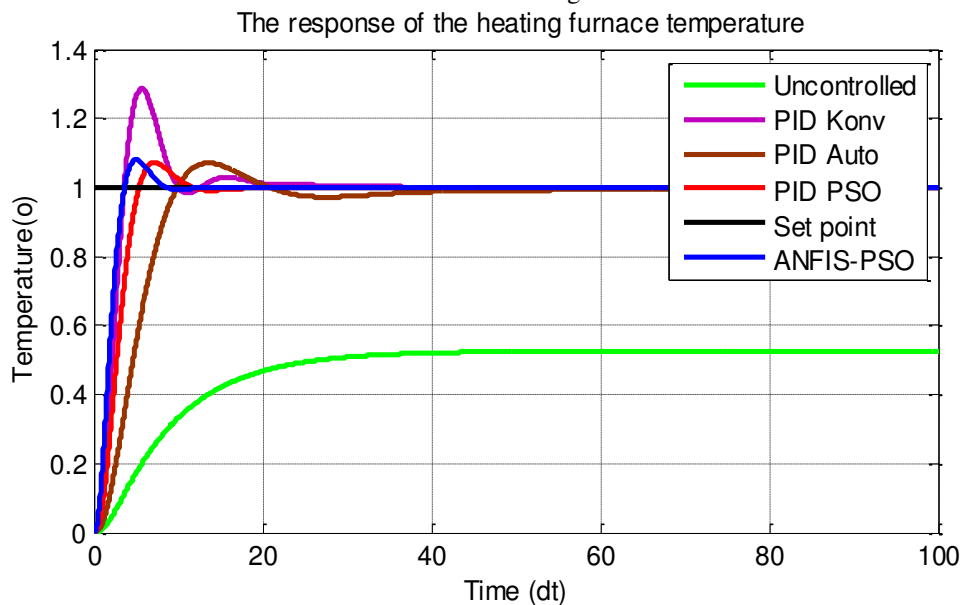


Figure 7. The response of the heating furnace temperature control at the switch position 1

As seen in Fig. 7, the PID-Auto controller has the smallest overshoot which is almost the same as that of PID-PSO and ANFIS-PSO. The smallest undershoot is found on PID-PSO and the fastest settling time is also on ANFIS-PSO. If being applied to the set point, the actual temperature increase at switch position 2 can be seen in Fig.8.

As indicated in Fig.8, the PID-Auto controller has the smallest overshoot which is almost the same as that of PID-PSO and ANFIS-PSO. The smallest undershoot is obtained using PID-PSO and the fastest settling time is also on ANFIS-PSO. Overshoot and undershoot that occurred can be seen in Table 1.

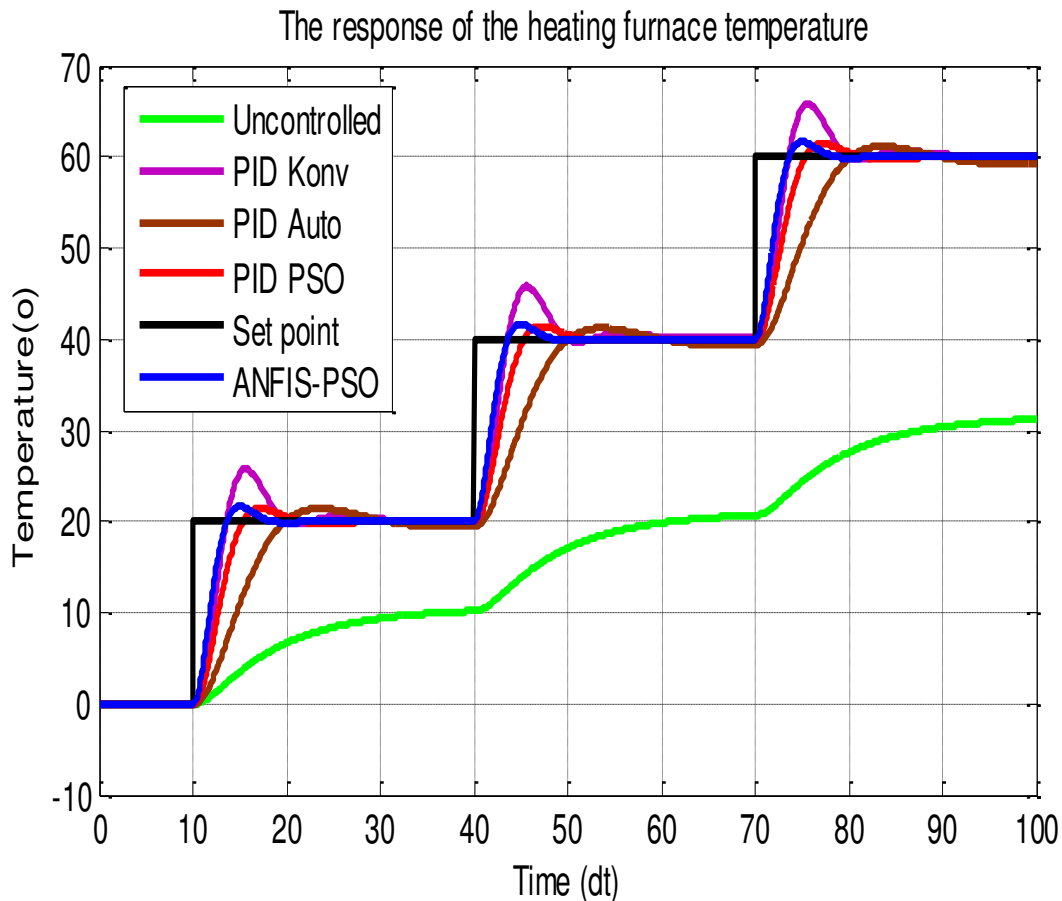


Figure 8. The response of the heating furnace temperature control at the switch position 2

Table 1. Response of each controller to temperature changes

	Uncontrolled	PID-Konv	PID-Auto	PID-PSO	ANFIS-PSO
Kp	-	1	4.2875	7.0177	-
Ki	-	1	0.1769	0.3486	-
Kd	-	0	1.1256	0.4323	-
Overshoot	0	0.2872	0.0720	0.0721	0.0722
Undershoot	0.4742	0.0161	0.0277	0.0081	0.0085
Settling time	~	38.4422	36.5342	30.4283	18.8789

As seen in Fig. 8 and Table 1, the smallest overshoot on PID-Auto is 0.0720, the smallest undershoot on PID-PSO is 0.0081, and the fastest settling time on ANFIS-PSO is 18.8789 seconds. The difference between overshoot and undershoot is relatively small. All methods indicate its readiness for implementation. However, the settling time of ANFIS-PSO is much shorter with relatively comparable value of overshoot and undershoot, so that it becomes the best optimization method to choose. Although PID-Auto produces a slightly smaller overshoot value, the settling time and undershoot are quite large, so PDI-PSO is chosen as the best method for controlling the temperature of the heating furnace.

IV. CONCLUSION

Design and implementation of the proposed ANFIS-PSO method to control the temperature of the heating furnace in this research brings to some conclusions that being compared to the other considered methods (Conventional PID (PID-Konv), Matlab Autotuning PID (PID-Auto), and PSO tuned PID (PID-PSO)), the ANFIS-PSO offers the best choice. Although the PID-Auto method provides the smallest overshoot and the PID-PSO offers the smallest undershoot, but the ANFIS-PSO results in the fastest settling time with almost the same values of overshoot and undershoot, and confirming the best method for optimizing the furnace temperature.

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