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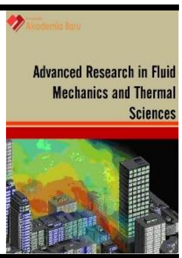

Model Optimization of a Shell and Tube Heat Exchanger by Using HGAPSO

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ABSTRACT

The demand to develop an efficient heat exchanger have been prompted in order to save the energy and materials as well as economic incentives within the industry. To establish a reliable heat exchanger that be able to operate under its normal operating conditions, a model should reflect the true behaviour of the process itself. Modelling of heat exchanger helps to understand process that occurs during the operation. Hence, the primary objective of the project is developing a structural model using an ARX (Auto-Regressive with eXogenous input) equation. The data from experiment was used to determine the parameter of ARX equation. Using HGAPSO (Hybrid Genetic Algorithm and Partical Swarm Optimization) algorithm, ARX parameters are optimized to obtain the transfer function that represents the plant for modelling. Validation test of autocorrelation and cross-correlation were used to validate between normalised data input and error. Based on the result on the six order model, parameter a0, a1, a2, a3, a4, and a5 values are -0.00083, -0.00202, -0.00253, -0.00095, -0.00213 and -0.00275 while parameter b0, b1, b2, b3, b4 and b5 values are -0.7642, -0.5759, 0.3118, 0.0715, 0.1140 and 0.0683 respectively. From validation test, all graphs are within the 95 percent of confident line.

1. Introduction

Heat exchanger is a heat transfer device that is used for transfer of thermal energy between two or more fluids available at different temperature. The heat exchanger will maintain it specific temperature conditions, which is achieved by controlling the exit temperature of one of the fluids (mainly hot fluid) in response to variations of the operating conditions [1]. In most heat exchangers, the fluids are separated by a heat transfer surface, usually a solid wall and ideally they do not mix or in direct contact. The wall may be simple plane wall or tube or complex configuration involving fins, baffles and multi-pass tube. It is commonly used in industries in almost all process and power plants to generate steam for the main purpose of electricity to generation via steam turbines [2-4]. Common

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examples of heat exchangers are familiar to us in day-to-day use are automobile radiators, condensers, evaporators, air preheaters, and oil coolers.

Shell and tube heat exchangers have been most widely used equipment in the industrial fields. It is the most versatile and used in conventional and nuclear power stations as condensers, steam generators in pressurized water reactor power plants, and feed water heaters. Hence, the real shell and tube heat exchanger will be used for this research project as it offers a great flexibility to meet almost any service requirement. Shell and tube exchanger are built with a bundle of round tubes mounted in a cylindrical shell with the tube axis parallel to that of the shell. One fluid will flows across and between the tubes, the other flows inside the inner tubes. The outlet temperature of the heat exchanger system need to be kept at a desired set point according to a process requirement. The major components of this exchanger are tubes (or tube bundle), shell, front-end head, rear-end head, baffles, and tube sheets. Typical parts and their arrangement are shown in Figure 1.

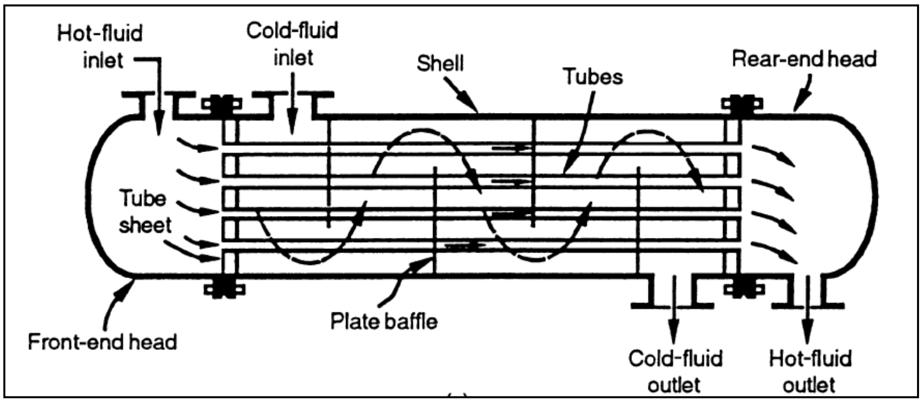


Fig. 1. Shell and tube heat exchanger [5]

System identification is known as a general process to develop a model for some particular system from a given input-output data and the process of deriving a mathematical system model from observed data in accordance with some predetermined criteria [5-6]. Model structure that will be used in this research is ARX (Auto-Regressive with eXogenous input) model structure. This model structure contained unknown parameters that linked the mathematical relationship between input and output variables. The parameters will be optimised by using HGAPSO (Hybrid Genetic Algorithm and Particle Swarm Optimization). Validation of identified model structure will be tested using autocorrelation and cross correlation test. It is important to determine how well the behaviour of the model corresponds to the data measured and the purpose for which the model used.

The purpose of the project is to optimize the model of a heat exchanger system based on system identification method. In this paper, a new hybrid genetic algorithm and partical swarm optimization (HGAPSO) is proposed to optimize the parameters of ARX model that could represent the modelling plant for the simulation process. Throughout the simulation process, HGAPSO algorithm will be compared with genetic algorithm (GA) and particle swarm optimization (PSO) algorithm to differentiate the optimization outcome. HGAPSO is programmed by MATLAB, and the results of the comparative algorithms are taken. As the model is based on the real data of a heat exchanger, it can represent the real heat exchanger plant. However, HGAPSO algorithm will need to be integrated with the real-time heat exchanger to see the working process. From the simulation process, all parameter values for ARX model and mean square error (MSE) value will be obtained and will be validate by using the validation test.

2. Modelling of Heat Exchanger

2.1 Heat Exchanger Plant Descriptions

The project is mostly concerned about the modelling of the open loop hot temperature of heat exchanger. The major function of the plant is to heat a liquid inside the heat exchanger. The heat is supplied by a hot water which is already heated in the boiler. While the temperature for cold water is maintained at room temperature. Preheated tank is used in the plant to keep warm the cold water. Inside the heat exchanger, a hot water will flows through a tube coiled inside a larger shell through which another, while colder water is running in the opposite direction. Heat is exchanged by the fluids where the hot water cools down and the cold water warms up, without them actually coming into contact and mixing. The temperature is around 25ºC and the preheated tank is maintaining the temperature at 60ºC. Hot water is heated in preheated tank (T12) with the temperature of 60ºC. Figure 2 shows the plant descriptions of heat exchanger. With reference to the overall schematic diagram, it is observed that the system consists of a number of tanks T11, T12, T13 and heat exchanger systems.

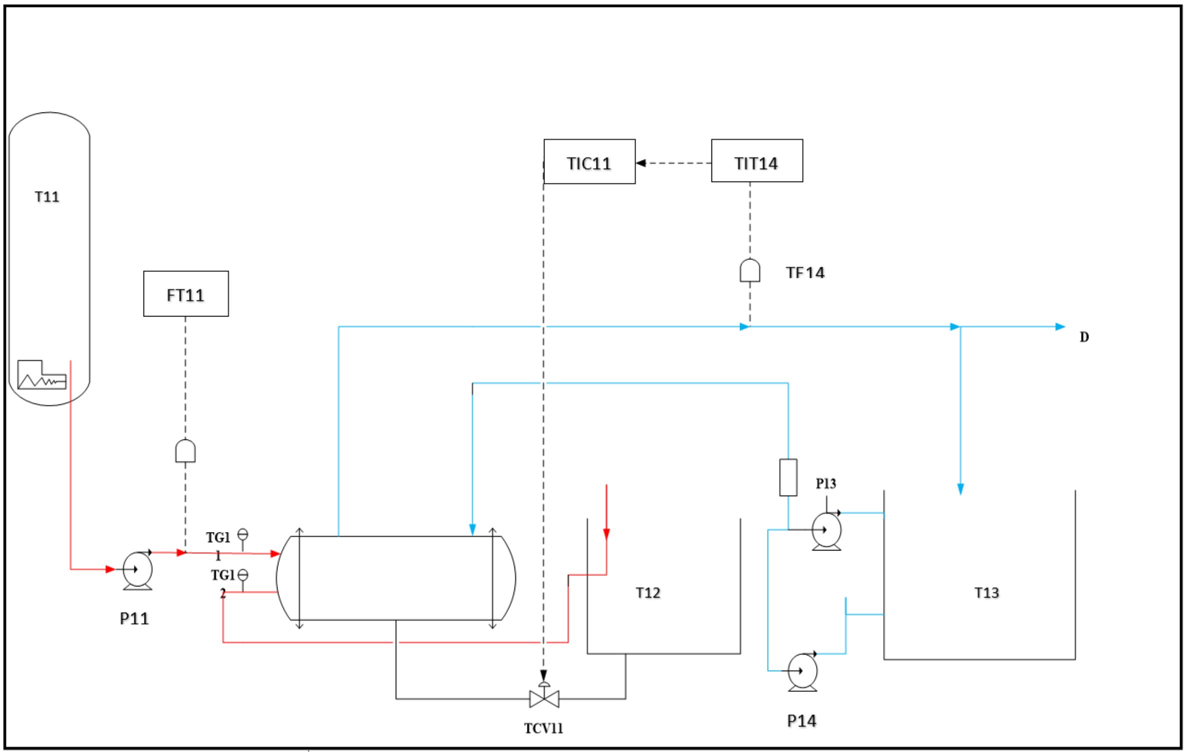


Fig. 2. Heat Exchanger Plant Description

2.2 System Identification Autoregressive Exogenous (ARX) Model Structure

System identification (SI) is a method to obtain a mathematical model of the dynamic system based on the experimental data. There are four crucial steps to determine model using SI. Firstly, by obtaining input and output data from the experiment. Secondly, performing a model structure. Third, applied the optimization method for the variable parameters. Lastly, do a model validation using autocorrelation and cross-correlation. This is to verify that the identified model fulfills the modeling requirement according to subjective and objective criteria of a good model approximation. The flow chart of identification is show in Figure 3.

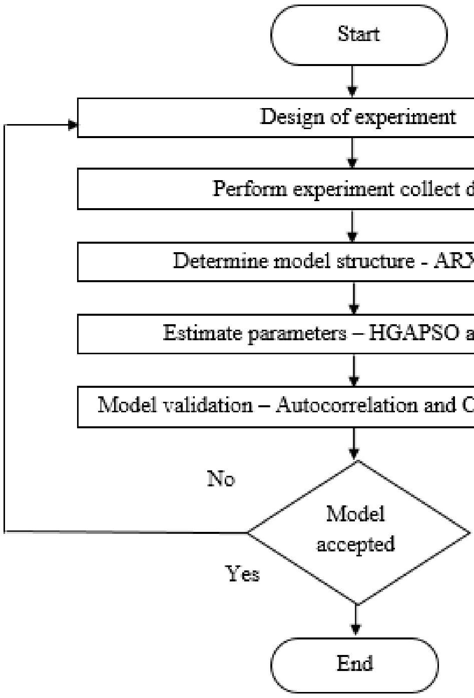


Fig. 3. Flow chart of Parameter Identification

In this paper, model structure that will represent the heat exchanger is ARX. This model is the simplest model includes the stimulus signal. The structure of an ARX model is show below in Figure 4.

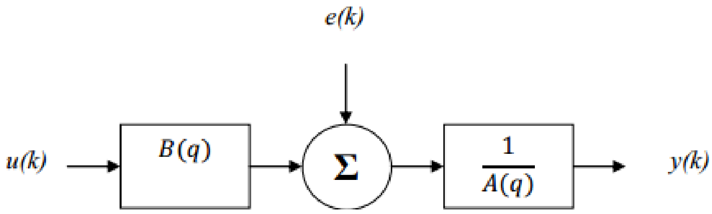


Fig. 4. The ARX Model signal flow

The model structure of ARX relates the current output $y(t)$ to a finite number of past outputs $y(t-k)$ and inputs $u(t-k)$. The structure is entirely defined by three n_a, n_b, and n_k. n_a is represent to the number of poles and n_b-1 is the number of zeros. Thus, n_k is the pure time delay (dead-time) in system. For system under sampled-data control occasionally n_k is equal to 1 if there is no dead-time. For multi input systems, n_a and n_b are row vectors. Which the i-th element gives the order delay associated with the ith input.

$$y(t) + a_1 y(t-1) + \cdots + a_{n_a} y(t-n_a) = b_1 u(t-n_k) + \cdots + b_{n_b} u(t-n_k-n_b+1) \quad (1)$$

The optimization method for the ARX model is done by using hybrid genetic algorithm and particle swarm optimization (HGAPSO). The HGAPSO algorithm combines the advantages of swarm intelligence of the PSO algorithm and the natural selection mechanism of the genetic algorithm in order to increase the number of highly evaluated agents at each iteration step.

2.3 Hybrid Genetic Algorithm and Particle Swarm Optimization (HGAPSO)

The idea of combining GA and PSO is not new. As can be seen, PSO and GA both work with an initial population of solutions and combining the searching abilities of both methods seems to be a reasonable approach. Originally, PSO functions according to knowledge of social interaction, and all individuals are taken into account in each generation. On the contrary, GA simulates evolution and some individuals are selected while some others are eliminated from generation to generation. Both algorithms have their own strengths and weaknesses. For example, while the GA method is more suitable for solving multiple objectives problems and is quite robust, its convergence speed is slow. The reason behind this is that the GA method requires evolutionary operators such as selection, crossover, and mutation for generation of solutions, thereby leading to a large number of function evaluations.

The strength of the PSO algorithm, on the other hand, is its fast convergence. This is because it simply uses mathematical operators instead of evolutionary operators for generation of solutions. This also leads to easier coding of the PSO algorithm in comparison to the GA method. The HGAPSO concept, which is combining of GA and PSO is simple and easily implemented in engineering applications. Previous research shows that the combination of two different algorithms increase the diversity of the solutions and the probability of getting trapped in the local optima, which is the main disadvantage of PSO, is decreased [7,8]. The optimisation using GA and PSO algorithm were also tested in other modelling cases [9,11].

The flowchart of the HGAPSO is shown in Figure 5. First, multiple solutions are generated randomly as initial population and objective function values are evaluated for each solution. After the evaluation is done, the population is divided into two subpopulations. One of these subpopulations is updated by the GA operation, while the other is updated by the PSO operation. New solutions created by each operation are combined in the next generation, and non-dominated solutions in the combined population are archived. The archive data is shared between the GA and PSO, i.e., non-dominated solutions created by the PSO can be used as parents in GA, while non-dominated solutions created by GA can be used as global guides in PSO.

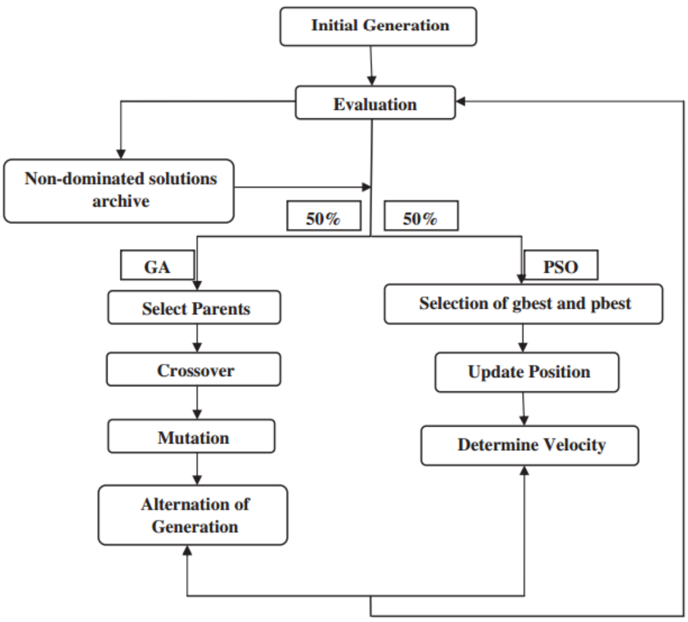


Fig. 5. The flow chart of HGAPSO

HGAPSO algorithm will be used to estimate the parameter value of ARX model. The parameters of the model process are assumed as constant in this algorithm. The heat exchanger plant will be in transfer function state. The transfer function will be linked to MATLAB Simulink. The sixth order of transfer function had been chose to represent the model of heat exchanger. To create the plant modelling in Simulink, standard signal was chose to be the input of model required. The type of standard signal used was step input standard signal.

2.4 Validation Test

For validation test, autocorrelation and cross-correlation are used. Correlation can be defined as the degree of similarity between two signals. It is widely used in digital signal processing. If the both signals are identical, then the correlation coefficient is equal to 1.

The autocorrelation is an operation that involves identical function and it may be viewed as a measure as similarity, or coherence, between a function $x(t)$ and it is shifted version [12]. Consider a random process $x(t)$ in example is continuous-time, it is autocorrelation is written as [13]:

$$R_{xx}(\tau) = \lim_{T\to\infty} \frac{1}{2T} \int_{-T}^{T} x(t)x(t+\tau)\,dt \tag{2}$$

While T, is equal to period of observation. $R_{xy}(\tau)$ is a real-valued and an even function with a maximum at $\tau = 0$.

While on the other hand, the Cross-correlation is very useful to investigate the degree of association between two signals [14]. The essential use of the cross-correlation function is providing measure of similarity. The similarities are between two signals which are a function of the delay between them. Both cross-correlation between $x(t)$ and $y(t)$ can be described by Taghizadeh [13].

$$\begin{gathered} R_{xy}(\tau) = \lim_{T\to\infty} \frac{1}{T} \int_{-T}^{T} x(t)y(t+\tau)\,dt \\ or \\ R_{yx}(\tau) = \lim_{T\to\infty} \frac{1}{T} \int_{-T}^{T} y(t)x(t+\tau)\,dt \end{gathered} \tag{3}$$

where T is the period of the observation and $R_{xy}(\tau)$ is a real valued. The auto- and cross-correlation are positively used as test validation in different models as in the researches of Salleh *et al.,* [15] and Mulyana *et al.,* [16].

2.5 Plant Modelling using HGAPSO

An identification method is performed by exciting the system using some input signal (such as step, sinusoid or random signal) and its input and output was observed over time interval. The input called FT11 data is the flow rate of heat exchanger. On the other hand, data of TIT14 is an output for temperature of heat exchanger. A plant of heat exchanger is use in term of transfer function to represent the plant. Figure 6 shows the picture of plant modelling of a heat exchanger in the MATLAB Simulink. To create the plant modelling in Simulink, standard signal was chose to be the input of model required and the type of standard signal used was step input standard signal.

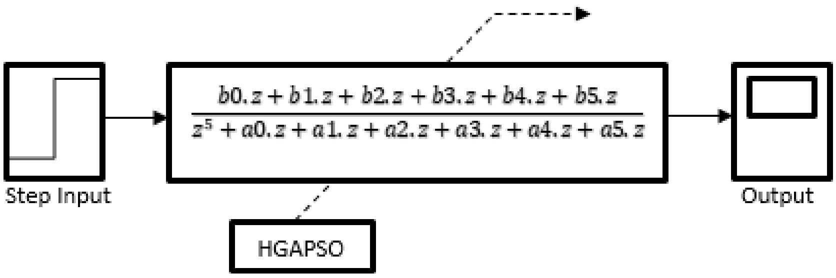


Fig. 6. Plant modelling of a heat exchanger

3. Results and Discussion

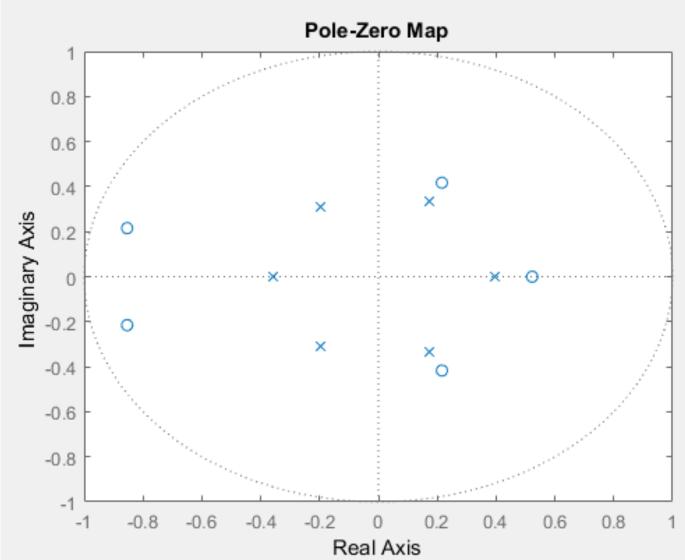
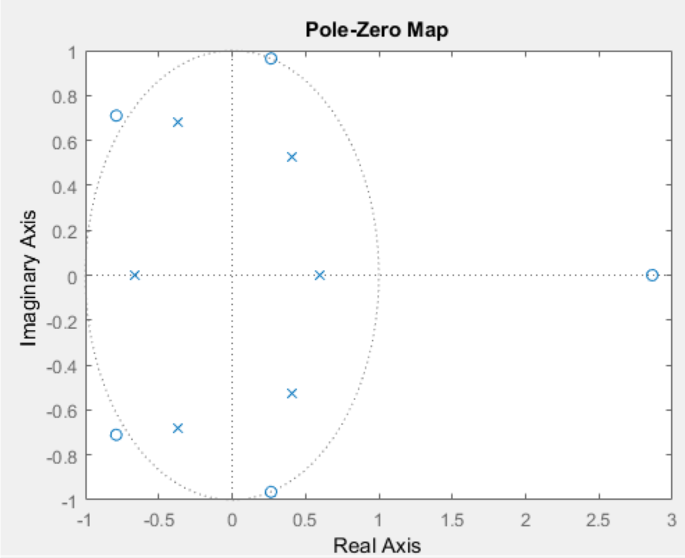
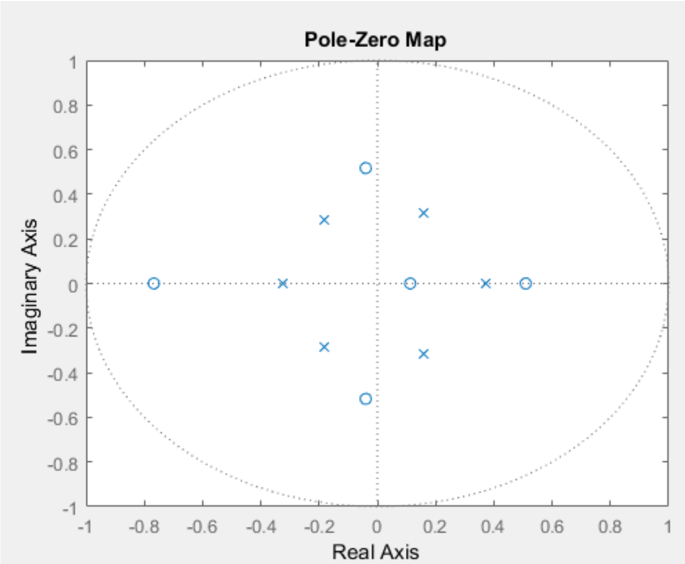
Based on the result that obtained from the heat exchanger experiment, an analysis has been made by using MATLAB programming. The parameter result is presented by values of a0, a1, a2, a3, a4, a5, b0, b1, b2, b3, b4 and b5 which will be used to make a transfer function model. The ARX parameters were optimise by using HGAPSO algorithm using MATLAB Simulink. This giving the model parameters a sixth order transfer function model. After getting all the value of the parameters, the transfer function is built by using all of these parameters. The letter 'a' is representing the output while the letter 'b' is representing the input. The transfer function obtained is in z-function.

$$tf = \frac{-0.7642z^5 - 0.5759z^4 + 0.3118z^3 + 0.07153z^2 + 0.114z + 0.0683}{-0.00083z^5 - 0.00202z^4 - 0.00253z^3 - 0.00095z^2 - 0.00213z - 0.00275} \quad (4)$$

For value mean square error (MSE), optimizing the parameter using HGAPSO gives the best value when compared with optimizing parameters using genetic algorithm (GA) and particle swamp optimization (PSO) itself. Table 1 shows the comparing MSE result for HGAPSO, GA and PSO using sixth order of transfer function. Attach to it is also P-Z Map to show the stability of the system. In a discrete-time, all the poles should lie inside the circle for the system to be stable.

For validation test, they are several graphs recorded. It includes autocorrelation graph, cross-correlation of input and residual graph, cross-correlation of input square and residual graph, cross-correlation of input square and residual square graph, and lastly, cross-correlation of residual and (input*residuals) graph. Figure 7 to Figure 11 show the graph result of autocorrelation and cross-correlation respectively. The result shows that the graph produced a smooth discrete time signal. For the cross-correlation test, all the graph need to examine at once. Validation test is said to be acceptable, when all the cross-correlation graph lies within the confident line.

Table 1
MSE and P-Z Map results for HGAPSO, GA and PSO

Result	MSE	P-Z Map
GA	0.003814	
PSO	0.01526	
HGAPSO	0.003742	

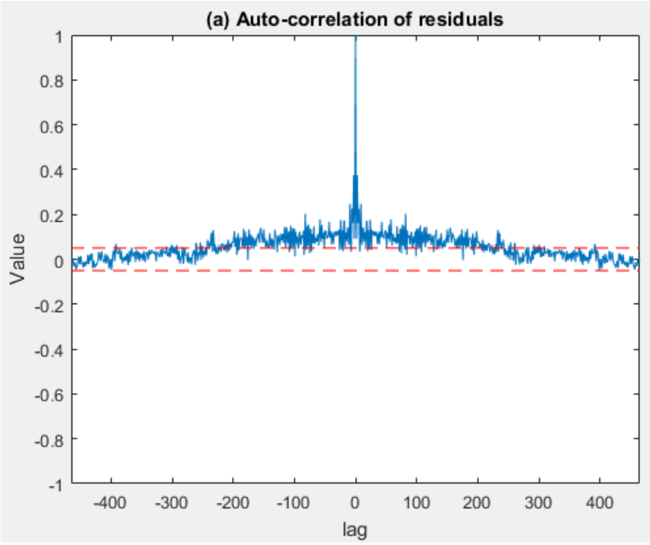


Fig. 7. Autocorrelation test

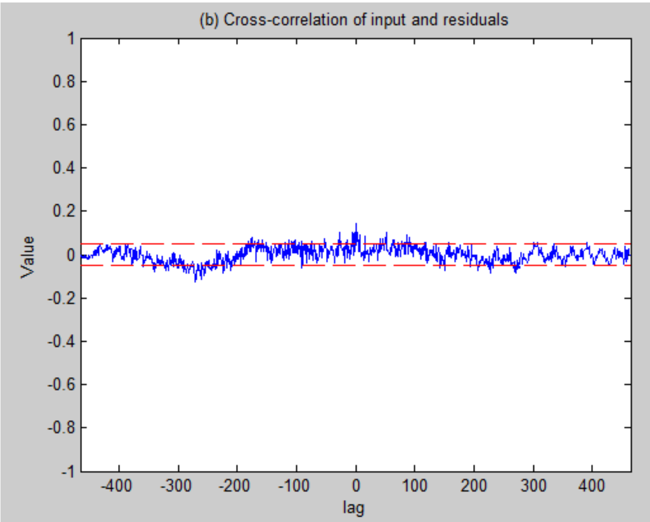


Fig. 8. Cross-correlation of input and residual

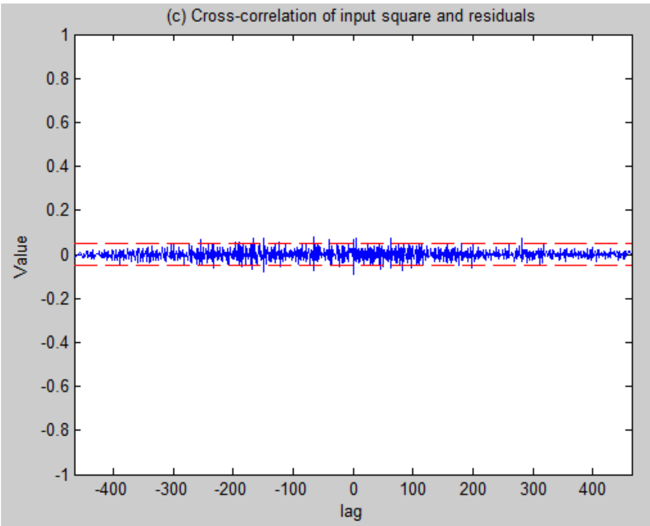


Fig. 9. Cross-correlation of input square and residual

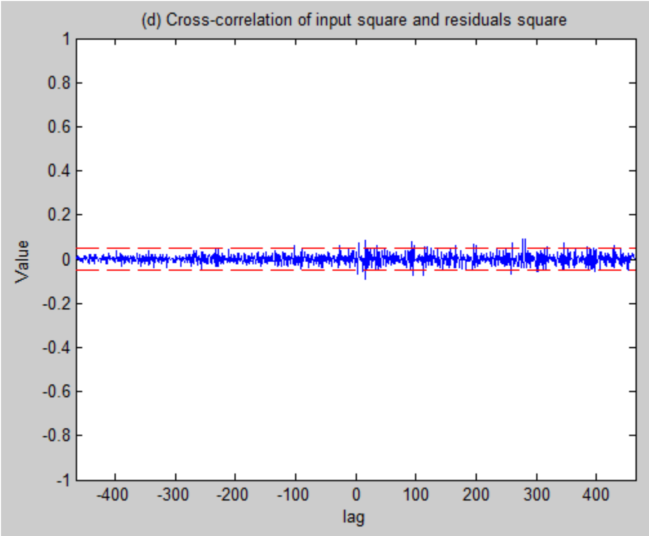


Fig. 10. Cross-correlation of input square and residual square

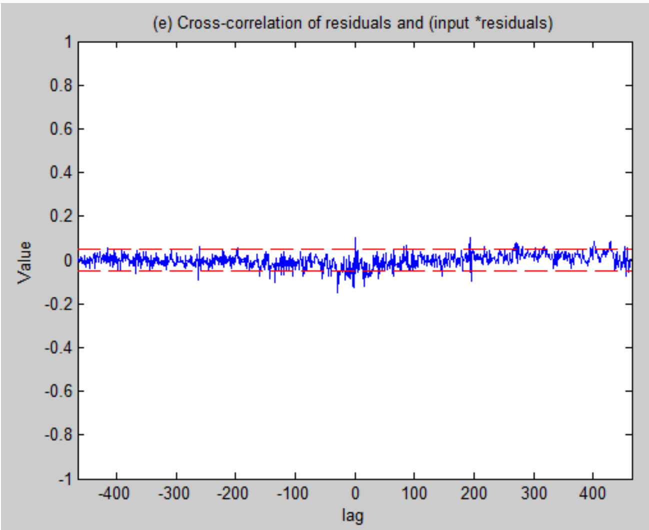


Fig. 11. cross-correlation of residual and (input*residuals)

4. Conclusions

As a conclusion there were about 582 data recorded from the recorder during the experiment of heat exchanger QAD model BDT92. The experiment was done at Control Laboratory, FKEE UTHM. In order to model the heat exchanger, model structure ARX equation was used and all the parameter variable was optimize using HGAPSO algorithm. There were 6 input parameters and 6 output parameters of ARX equation obtained in this project where the input and the output were represent as 'a' and 'b'. The parameter input obtained for a0, a1, a2, a3, a4, and a5 values were -0.00083, -0.00202, -0.00253, -0.00095, -0.00213 and -0.00275 and the output parameter for b0, b1, b2, b3, b4 and b5 values were -0.7642, -0.5759, 0.3118, 0.0715, 0.1140 and 0.0683 respectively. The parameters obtained will be used as the modelling plant for simulation process that represent the heat exchanger itself. The MSE's value obtained by using HGAPSO algorithm shows the least value when compared with GA and PSO algorithm. Hence, it is proved that HGAPSO be able to optimize the model of heat exchanger much better. It is important to understand that, minimum value of MSE shows that the effectiveness of heat exchanger process. For validation test of a model, note that all graph produced a smooth discrete time signal and all line lies within the 95 percent of confident line.

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