MODELING AND CONTROL OF HEAT EXCHANGER BY USING BIO-INSPIRED ALGORITHM

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ABSTRACT

Heat exchanger is a heat transfer device that is used for transfer of thermal energy between two or more fluids available at different temperature. Based on the previous study referred, the same data of heat exchanger had been used but different types of model were used to find the structural model of heat exchanger. The main objective of this study is to obtain structural model using ARMAX equation and optimize the value of PID parameters. In this study, data from heat exchanger experiment was used to determine the parameter of ARMAX equation and by using GA and PSO, all the parameters were optimized. Transfer function obtained will be used for plant modelling. Validation test used to validate between normalised data input and error. Validation test used were autocorrelation and cross-correlation. Finally, applying PID controller onto plant modelling to optimize the value of Kp, Ki and Kd. The analysis shows that MSE value produce from GA is 0.0035473 while PSO's MSE value is 0.0043595. ARMAX parameters were obtained by using GA and PSO with 4 inputs (a0, a1, a2, and a3) and 4 outputs (b0, b1, b2 and b3). For GA, the inputs are -0.000214, -0.000728, -0.0020, and -0.000804 while the outputs are -1.0000, -0.1783, -0.1473 and 0.3248. For PSO, the inputs are 0.0104, -0.0122, -0.0067 and 0.0118 while the outputs are -0.4274, -0.1256, -0.1865 and -0.2614. From the validation test, GA produced smoother and effective result compared to PSO with less noise exists. By attaching PID controller, all the parameters value (Kp, Ki, and Kd) was optimized. For GA, the parameters are -0.5567, -54.1127 and 0.0005. For PSO, the parameters are -0.2846, -56.4346 and 0.0010. Even though both algorithms produced different simulation results, both of them succeed to reduce the result before attaching PID controller. As a conclusion, GA produces better result compared to PSO.

ABSTRAK

Penukar haba adalah alat pemindahan haba yang digunakan untuk pemindahan tenaga haba antara dua atau lebih cecair pada suhu yang berbeza. Berdasarkan rujukan kajian sebelum ini, data penukar haba yang sama telah digunakan tetapi berbeza jenis model yang digunakan untuk mencari model struktur. Objektif utama kajian ini adalah untuk mendapatkan model struktur dengan menggunakan persamaan ARMAX dan mengoptimumkan nilai parameter PID. Dalam kajian ini, data dari penukar haba eksperimen telah digunakan untuk menentukan parameter persamaan ARMAX dan dengan menggunakan GA dan PSO, semua parameter telah dioptimumkan. Rangkap pindah yang diterima akan digunakan untuk pemodelan tumbuhan. Ujian validasi digunakan untuk mengesahkan antara input data pulih dan kesilapan. Ujian validasi yang digunakan adalah autokorelasi dan silang korelasi. Akhir sekali, memohon pengawal PID ke pemodelan tumbuhan untuk mengoptimumkan nilai Kp, Ki dan Kd. Analisis menunjukkan bahawa nilai MSE hasil dari GA adalah 0.0035473 manakala nilai MSE PSO adalah 0.0043595. Parameter ARMAX diperolehi dengan menggunakan GA dan PSO adalah 4 input (a0, a1, a2, dan a3) dan 4 output (b0, b1, b2 dan b3). Untuk GA, data masuk adalah -0.000214, -0.000728, -0.0020, -0.000804 manakala data keluar adalah -1.0000, -0.1783, -0.1473, 0.3248. Untuk PSO, data masuk adalah 0.0104, -0.0122, 0.0067, 0.0118 manakala data keluar adalah -0.4274, -0.1256, -0.1865, -0.2614. Daripada ujian pengesahan, GA menghasilkan hasil licin dan berkesan berbanding dengan PSO dengan kurang bunyi. Dengan melampirkan pengawal PID, semua nilai parameter (Kp, Ki, dan Kd) telah dioptimumkan. Untuk GA, parameter -0.5567, -54.1127 and 0.0005. Untuk PSO, parameter -0.2846, -56.4346 and 0.0010. Walaupun kedua-dua algoritma menghasilkan keputusan simulasi yang berbeza, mereka berjaya untuk mengurangkan hasil keputusan. Kesimpulannya, GA menghasilkan keputusan yang lebih baik berbanding dengan PSO.

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CHAPTER 1

INTRODUCTION

1.1 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. 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 (Yiu,2007). In most heat exchangers, the fluids are separated by a heat transfer surface, and ideally they do not mix or in direct contact. Common examples of heat exchangers are familiar to us in day-to-day use are automobile radiators, condensers, evaporators, air preheaters, and oil coolers (Sha,2003).

The most commonly used types of heat exchanger in industries are shell and tube heat exchanger. It consists of a bundle of tubes and a shell. One fluid that needs to be heated or cooled will flows through the tubes and the second fluid runs over the tubes that provides the heat or absorbs the heat required (Sha,2003). Heat transfer for both fluids are depends on its flow velocity. The primary heating medium commonly used for heat exchanger is water vapor because it is inexpensive and readily available. Many plants that carry out the process of heat transfer have a boiler to produce water vapor and the cooling medium that usually used is also water.

During the process, the heating medium will flow through the inlet tube shell of heat exchanger while the cooling medium will flow through the outer shell which surrounds the tube of heat exchanger. As mentioned before, both heating and cooling medium will not mix together. It is mean that there are two tubes and vessels inside the heat exchanger where the heating medium will flow using the inside tube while the cooling medium flow using the outside tube of heat exchanger.

The hot fluid transfers its heat to a conductive surface between it and cold chamber; subsequently the partition transfers the heat to the cold fluid. This follows the second law of thermodynamics which states that the heat always flows from a higher to a lower temperature. The real system of heat exchanger that will be used in this project is a shell and tube type of heat exchanger. The detail flow process of heat exchanger will be deeply discussed in Chapter 2.

1.2 Problem Statement

From previous research, in order to identify a model structure of heat exchanger, a lot of methods had been used such as ARMAX method, RELS method, AR method and polynomial method to derive the relationship between input and output obtained. It uses the same data but different types of model.

In this project, method that will be used in order to find the structural model for heat exchanger is ARMAX model. Genetic Algorithm (GA) and Particle

Swarm Optimization (PSO) will be used to optimize the values of each parameter involves. Both structural models will be compared to see its validation using autocorrelation and cross-correlation. If both structural fit perfectly, the project will then be continue with applying the PID controller.

1.3 Objective

In order to accomplish this project, there are a few objectives that have to be achieved. The objectives include;

1. To obtain a mathematical model of heat exchanger by using ARMAX equation.
2. To validate input and output data value from heat exchanger.
3. To obtained the value of Kp, Ki and Kd of PID controller in order to control the system.

1.4 Scope of study

The scopes of this study include;

1. Implement ARMAX model in heat exchanger
2. Optimize parameters using Genetic Algorithm (GA) and Particle Swarm Optimization (PSO).
3. Validate the model with autocorrelation and cross-correlation test.
4. Using MATLAB PID tuner to obtained the value of Kp, Ki and Kd.

1.5 Expected Outcome

The expected result of this project is to design the experiment and obtain the data of Heat Exchanger through experimental design. The data obtained is used to find the transfer function of plant. Another approach that will be used to find transfer function is using ARMAX model. During the process, Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) will be used to optimize the parameters value of ARMAX model. Therefore, we could obtain the parameter values and hence the transfer function between plant and ARMAX model can be compared.

1.6 Organisation of Dissertation

The content of this dissertation are organized into three chapters for this Master Project 1 and each chapter is written to be largely self-contained and complete.

Chapter 1 will go through the introduction about heat exchanger basic process. The idea is to be able to understand how the heat exchanger works. Hence, the process of obtaining data from the machine is much easier. Furthermore, the problem statement of this project also discussed as a guideline how the project will carry out to overcome the problem. Next, the research objectives and the research scopes are defined.

Before performing the detail of project process, detail explanation about the heat exchanger process will be discussed in Chapter 2. Furthermore, important elements that involved in this project also will be explained. For examples, the identification system involved, the optimization system used and the validation test upon the result produced. The important parts are the previous works done by other researchers are explored.

For Chapter 3, it describes the methodology involves in conducting the project in order to achieve the objectives of the project. The detail about plant description and experiment design will be discussed in this chapter. Furthermore, summary of genetic algorithm (GA) and particle swarm optimization (PSO) process also will be include to show the process during optimization of parameter involves.

For Chapter 4, it described the result obtained and discussed the cause of it. The detail about analysis of result will also be discussed in this chapter. The important part is, we can compared the result obtain for GA and PSO. Furthermore, we can also compare the plant results with and without PID controller. Parameters of ARMAX model and PID controller also could be optimized.

For Chapter 5, it described the conclusion and recommendations of this project. The conclusion is important to conclude all the result obtained. The recommendation is to give an idea for further research and improving the project.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The needs for energy and materials savings, as well as economic incentives, have prompted the need to develop more efficient heat exchangers. A preferred approach to the problem of increasing heat exchanger efficiency, while maintaining minimum heat exchanger size and operational cost, is to increase heat exchanger rate.

The heat exchanger is a device built for efficient heat transfer from one fluid to another, whether the fluids are separated by a solid surface or the fluids are directly contacted. One of the heat exchanger types that are commonly used in the process is shell and tube exchanger. For this project, the real system of heat exchanger that will be used is the shell and tube exchanger type.

These types of heat exchanger are widely used in process industrial applications. 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. They offer great flexibility to meet almost any service requirement. It can also be designed for high pressures relative to the environment and high pressure differences between the fluid streams. However, they are a lot of heat exchanger types offer in the industry. The other types of heat exchanger will be explained in the next subtopic.

2.2 Heat Exchanger Description

A heat exchanger is a device that is used for transfer of thermal energy (enthalpy) between two or more fluids, between a solid surface and a fluid, or between solid particulates and a fluid, at differing temperatures and in thermal contact (Ogata, 1998). The fluids may be single compounds or mixtures. Typical applications involve heating or cooling of a fluid stream, evaporation or condensation of a single or multicomponent fluid stream, and heat recovery or heat rejection from a system (Chong,2000).

A heat exchanger consists of heat exchanging elements such as a core or a matrix containing the heat transfer surface, and fluid distribution elements such as headers, manifolds, tanks, inlet and outlet nozzles or pipes, or seals. Usually there are no moving parts in a heat exchanger; however, there are exceptions such as a rotary regenerator (in which the matrix is mechanically driven to rotate at some design speed), a scraped surface heat exchanger, agitated vessels, and stirred tank reactors (Kakac,2012).

In most heat exchangers, the fluids are separated by a heat exchanger surface, and ideally they do not mix. Although heat flows from hot fluid to cold fluid by thermal conduction through the separating wall, heat exchangers are basically heat convection equipment. Convection within a heat exchanger is always forced, and may be with or without phase change of one or both fluids. The basic designs for heat exchangers are the shell-and-tube heat exchanger and the plate heat exchanger, although many other configurations have been developed. According to flow layout, heat exchangers are grouped in (Thulukkanam,2000):

a) Shell-and-tube heat exchanger (STHE), where one flow goes along a bunch of tubes and the other within an outer shell, parallel to the tubes, or in cross flow. Figure 2.1a shows a typical example of STHE.

b) Plate heat exchanger (PHE), where corrugated plates are held in contact and the two fluids flow separately along adjacent channels in the configuration. Figure 2.1b shows details of the interior of a PHE.

c) Open-flow heat exchanger, where one of the flows is not confined within the equipment. They originate from air-cooled tube-banks, and are mainly used for final heat release from a liquid to ambient air, as in car radiator, but also used in vaporizers and condensers in air-conditioning and refrigeration applications, and in directly fired home water heaters. Figure 2.1c shows the example of open-flow heat exchanger.

d) Contact heat exchanger, where the two fluids enter into direct contact. Furthermore, the contact can be continuous such as when the two fluids mix together and then separate by gravity forces, as in a cooling tower, or the contact can be alternatively with a third medium, usually solid, as in regenerative heat exchangers, like the rotating wheel. Figure 2.1d shows the hot gas heats the wheel whereas the cold gas retrieves that energy.

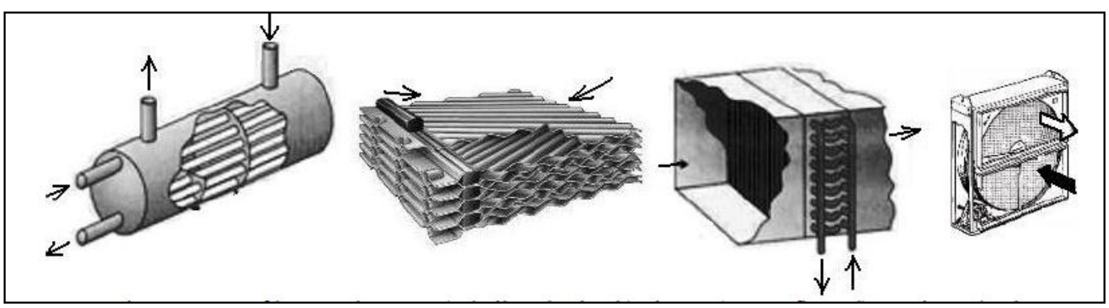

Figure 2.1: Types of heat exchanges: a) shell-and-tube, b) plates, c) open-flow, d) rotating-wheel (Thulukkanam,2000).

For this project, we are focusing on shell-and-tube exchanger types. This exchanger, shown in Figure 2.2, is generally built of a bundle of round tubes mounted in a cylindrical shell with the tube axis parallel to that of the shell. One fluid flows inside the tubes, the other flows across and along the tubes. The major components of this exchanger are tubes (or tube bundle), shell, front-end head, rear-end head, baffles, and tube sheets.

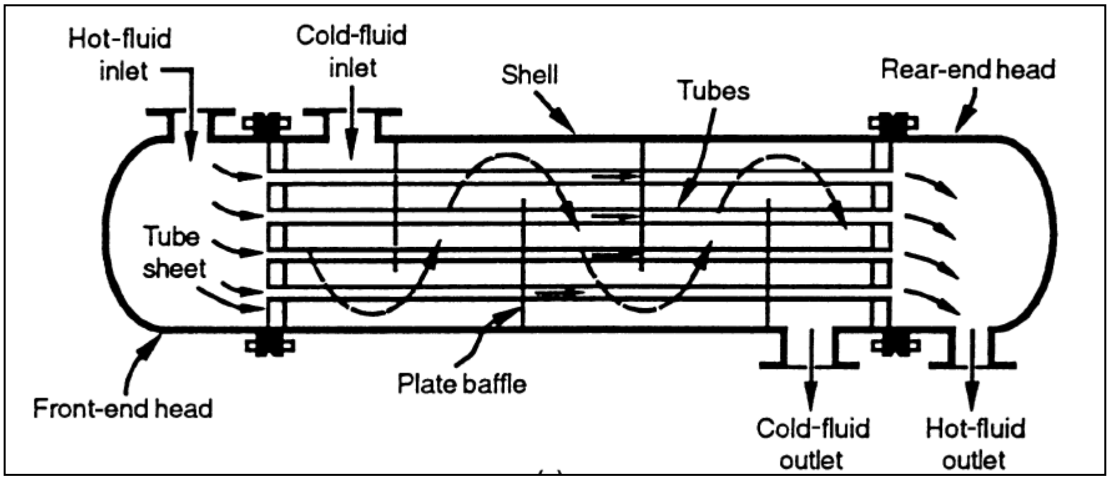

Figure 2.2: Shell-and-tube exchanger (Thulukkanam,2000).

Varieties of different internal constructions are used in shell-and-tube exchangers, depending on the desired heat transfer and pressure drop performance and the methods employed to reduce thermal stresses, to prevent leakages, to provide for ease of cleaning, to contain operating pressures and temperatures, to control corrosion, to accommodate highly asymmetric flows, and so on (Chong 2000). They are the most versatile exchangers made from a variety of metal and nonmetal materials (graphite, glass, and Teflon) and in sizes from small (0.1m^2, 1ft^2) to super giant (over 100,000m^2, $10^6 ft^2$) (Thulukkanam,2000). Here are the main advantages of shell-and-tube heat exchanger:

a) Condensation or boiling heat transfer can be accommodated in either the tubes or the shell, and the orientation can be horizontal or vertical.
b) The pressures and pressure drops can be varied over wide range.

c) Thermal stresses can be accommodated inexpensively.
d) The shell and tubes can be made of different materials.
e) Cleaning and repair are relatively straightforward, because the equipment can be dismantled for this purpose.

Therefore, the shell-and-tube heat exchangers are widely used in the industry since it offers a great flexibility to meet almost any service requirement.

2.3 MATLAB Software

The MATLAB® high-performance language for technical computing integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expected in familiar mathematical notation. It is high-level technical computing language and interactive environment for algorithm development, data visualization, data analysis, and numeric computation. MATLAB is stands for matrix laboratory and is used in a wide range of applications. It is was originally written to provide easy access to matrix software developed by the LINPACK and EISPACK projects, which together represent the state-of-the-art in software for matrix computation.

It features a family of application-specific solutions called toolboxes. Very important to most users of MATLAB, toolboxes allow people to learn and apply specialized technology. Toolboxes are comprehensive collections of functions (M-files) that extend the environment to solve particular classes of problems. Areas in which toolboxes are available include signal processing, control systems, neural networks, fuzzy logic, wavelets, simulation, and many others (Jimenez,2008). The interface is shown in Figure 2.3.

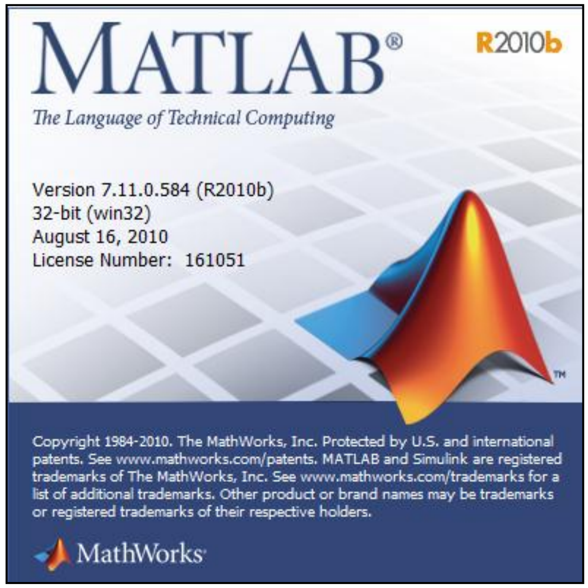

Figure 2.3: MATLAB R2010b Version

2.4 System Identification – ARMAX Model

System identification is the general process of developing a model for some particular system from given input-output data and the process of deriving a mathematical system model from observed data in accordance with some predetermined criterion. To solve this system identification, there are a lot of structures such as ARX (Autoregression with exogenous input) model, ARMAX (Autoregression moving average exogenous input) model, OE (Output Error) model and general polynomial model. In this project, the selected model structure that will be used is ARMAX model and estimation algorithm using Genetic Algorithm (GA) and Particle Swarm Optimization (PSO).

The model for this identification is heat exchanger QAD BDT 921. For model validation, the identified model will be test using autocorrelation test and cross-correlation test. It is to verify that the identified model fulfills the modeling requirement according to subjective and objective criteria of good model approximation. The input-output data are sometimes recorded during a specifically designed identification experiment, where the user may determine which signals to measure them and may also choose the input signals. The objective with experiment design is thus to make these choices so that the data become maximally informative, subject to constraints that may be at hand. In other cases the user may not have the possibility to effect the experiment, but must use data from the normal operation of the system.

Parametric system identification is the fitting of model parameters to a pre-selected model by using input output data. The qualitative information by non-parametric can be used to select the proper model structure. Parametric identification can be seen as identifying the optimal parameters of a filter of pre-determined order. The parameter identified by the system is the best approximation to the real model parameters with respect to a certain criteria such as the minimum of norm between the estimate and validation. Most of the parametric methods can be described as variant of the general linear parametric model for single-output system in Figure 2.4.

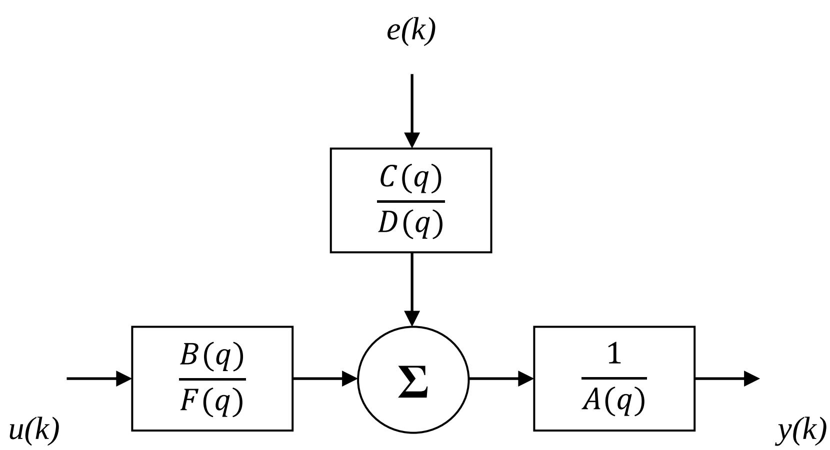

Figure 2.4: General Linear Parametric Model

Where the discrete shift operator, u(k) is the input, e(k) is the noise and disturbance, y(k) is the output and A(q), B(q), C(q), D(q) and F(q) are polynomials in shift operator (z or q). The general structure is defined by giving the time-delays n_k and the orders if the polynomials.

In this project, ARMAX (Autoregressive moving average exogenous) is selected as a model structure. The structure of an ARMAX model is show below in Figure 2.5.

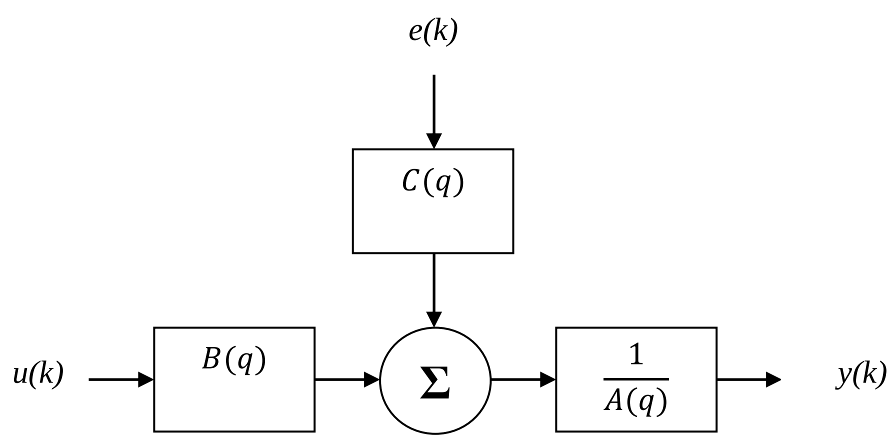

Figure 2.5: The ARMAX Model Structure

The ARMAX model structure is equation (2.1),

$$y(t) + a_1 y(t-1) + \cdots + a_{n_a} y(t-n_a) =$$
$$b_1 u(t-n_k) + \cdots + b_{n_b} u(t-n_k-n_b+1) +$$
$$c_1\, e(t-1) + \cdots + c_{n_c}\, e(t-n_c) + e(t) \qquad (2.1)$$

Where:

y(t): Output at time t

n_a: Number of poles

n_b: Number of zeroes plus 1

n_c: Number of C coefficients

n_k: Number of input samples that occur before the input affects the output. Also called the dead time in the system.

$(t-1)-\cdots y(t-n_a)$: Previous outputs on which the current output depends

$u(t-n_k)-\cdots u(t-n_k-n_b+1)$: Previous and delayed inputs on which the current output depends

$e(t-1)-\cdots u(t-n_c\ )$: White-noise disturbance value

The models constitute an important class of difference equation on the form in equation (2.2) (Kachitvichyanukul 2012).

$$A(q^{-1})y_k = q^{-d}B(q^{-1})u_k + C(q^{-1})e_k \qquad (2.2)$$

Where d is s time delay and A, B, C are polynomials as equation (2.3).

$$\begin{aligned} A(q^{-1}) &= 1 + a_1q^{-1} + \cdots + a_{na}q^{-na} \\ B(q^{-1}) &= b_0 + b_1q^{-1} + \cdots + a_{nb}q^{-nb} \\ C(q^{-1}) &= 1 + c_1q^{-1} + \cdots + a_{nc}q^{-nc} \end{aligned} \qquad (2.3)$$

The parameters na, nb, and nc are the orders of the autoregressive ARMAX model, and nk is the delay, q is the delay operator. The adjustable parameters are written in equation (2.4).

$$\theta = [a_1\ a_2\ \dots\ a_{na}\ b_1\ \dots\ b_{nb}\ c_1\ \dots\ c_{nc}]^T b \qquad (2.4)$$

Only special case of the ARMAX model that admits a reformulation to the linear regression model is the controlled autoregressive model (ARX) as the equation (2.5).

$$A(q^{-1})y_k = q^{-d}B(q^{-1})u_k + e_k \qquad (2.5)$$

Where ek is white noise. Hence, there is no immediate reformulation of the general ARMAX model that results in a linear regression model $y = \emptyset\theta + \nu$ unless the disturbances {ek} are available to measurement.

The ARMAX models include several interesting special cases such as the autoregressive (AR) model. If the data is a time series, which has no input channels and one output channel, then armax calculates an ARMAX model for the time series as an equation (2.6).

$$A(q^{-1})y_k = e_k \tag{2.6}$$

This is effective to model harmonics confounded with noise. The moving average (MA) model that is show in equation (2.7),

$$y_k = C(q^{-1})e_k \tag{2.7}$$

is another type that is popular in signal processing as a basic for filter design (FIR) and the identification of truncated impulse responses. The ARMAX model equation is show in equation (2.8).

$$A(q^{-1})y_k = C(q^{-1})e_k \tag{2.8}$$

The mathematical expression of the generalized structure is written in equation (2.9).

$$y(k) = \frac{B(q)}{A(q)}u(k) + \frac{C(q)}{A(q)}e(k) \tag{2.9}$$

An ARMAX model structure includes disturbance dynamics. ARMAX models are useful when have dominating disturbances that enter early in the process, such as at the input. The parameters that need to fine are the coefficients in the ARMAX model structure which is A, B and C polynomials. An ARMAX has been selected in this project because it has a suitable model structure that can give an accurate data which can be to compare the output, input and error data and it is a model that explains a dependent variable out of lagged (Hannan,1980).

2.5 Genetic Algorithm (GA)

The concept of genetic algorithm (GA) was developed by Holland and his colleagues in the 1960s and 1970s (Holland,1975). GA is inspired by the evolutionist theory that explains the origin of species. Basically, in nature the weak and unfit species within their environment will face with extinction by natural habits. The strong and capability ones have greater opportunity to pass their genes to future generations via reproduction. Occasionally, when the evolutions of gene process are slow, random changes within the population may occur. If the new species that evolve from the old one have their additional advantages, they may succeed in the survival challenge. The unsuccessful one will be eliminated by the natural selection.

Genetic Algorithms are search and optimization techniques inspired by two biological principles namely the process of “natural selection” and the mechanics of “natural genetics” (Hong,2002). GAs will manipulate not only one potential solution to a problem but a lot of potential solutions which called as population. The potential solution is refer to chromosomes and chromosomes are represents all the parameters of the solution. Each chromosomes will be compared each other in the population and fitness between them indicates the successful chromosomes.

GA operates with a collection of chromosomes, called a population. Typically, it initialized with a random population consisting of between 20 to 100 individuals. As the search evolves, the population includes fitter and fitter solutions, and eventually it converges, meaning that it is dominated by a single solution. Holland also presented a proof of convergence (the scheme theorem) to the global optimum where chromosomes are binary vectors (Holland,1975). There are three main stages of a genetic algorithm; these are known as reproduction, crossover and mutation (Ibrahim,2005). All main stages will be explained below:

a) *Reproduction*: During the reproduction phase, the fitness value of each chromosome is assessed. This value is used in the selection process to provide bias towards fitter individuals. Just like in natural evolution, a fit chromosome has a higher probability of being selected for reproduction.
b) *Crossover*: Once the selection process is completed, the crossover algorithm is initiated. The crossover operations swap certain parts of the two selected strings in a bid to capture the good parts of old chromosomes and create better new ones. Genetic operators manipulate the characters of a chromosome directly, using the assumption that certain individual's gene codes, on average, produce fitter individuals.
c) *Mutation*: Mutation operator introduces random changes into characteristics of chromosomes. Mutation is generally applied at the gene level. In typical GA implementations, the mutation rate is very small typically less than 1%. Therefore, the new chromosome produced by mutation will not be very different from the original one.

The main idea of GA is to mimic the natural selection and the survival of the fittest. In GA, the solutions are represented as chromosomes. The chromosomes are evaluated for fitness values and they are ranked from best to worst based on fitness value. The process is shown in Figure 2.6 below (Kohn,1998):

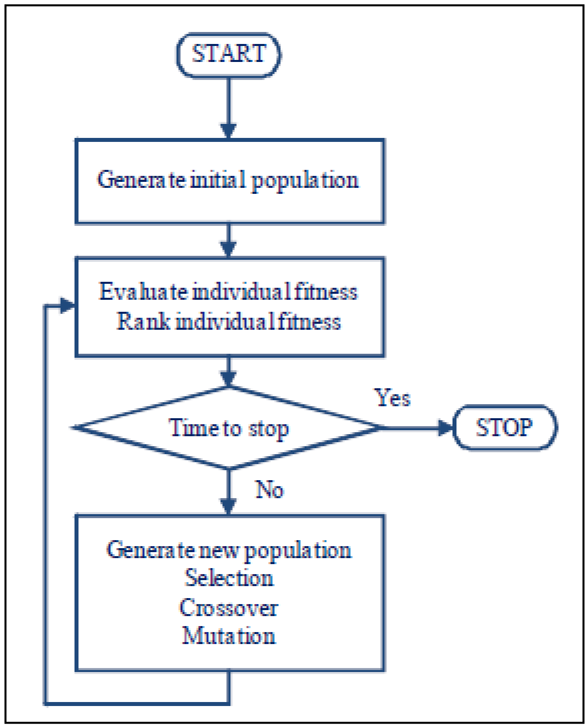

Figure 2.6: Flowchart of Genetic Algorithm (Kohn,1998).

The process starts with better chromosomes are selected with higher probabilities than the chromosomes with poorer fitness. The selection probabilities are usually defined using the relative ranking of the fitness values. Once the parent chromosomes are selected, the crossover operator combines the chromosome of the parents to produce new offspring. Since fitter individuals are being selected more often, there is a tendency that the new solutions may become very similar after several generations, and the diversity of the population may decline; and this could lead to population stagnation. Mutation is a mechanism to inject diversity into the population to avoid stagnation.

2.6 Particle Swarm Optimization (PSO)

The Particle Swarm Optimization is one of the stochastic optimization techniques. PSO is based on the social and personal behavior of a swarm. It was first introduced by Eberhart and Kennedy (Kennedy,2001). The researcher described how PSO can be applied to a nonlinear optimization problem through the simulation of a social system characterized by swarms. PSO would continuously search for a new position for each swarm based on their social best position and self best position. The word “swarm” comes from the irregular movements of the particles in the problem space, now more similar to a swarm of mosquitoes rather than a flock of birds or a school of fish (Valle,2006).

PSO and evolutionary computation techniques, like a Genetic Algorithm, are especially similar. Both algorithms would work by searching solutions enhanced with updating generations. However, there is nothing to the equivalent of ‘evolution operators’ in PSO, which is common in Genetic Algorithm (Engelbrecht 2006). PSO is also being used in system identification problems. Huang and colleagues have demonstrated that PSO can be used for identifying as ARMAX model for Short-term Load Forecasting (Huang,2005). The basic of PSO algorithm is described by Equation 2.10 and Equation 2.11 (Gautam,2010).

$$v_{k+1}^{i} = wv_{k}^{i} + a_1u_1 \times \left[Pbest_{k}^{i} - R_{k}^{i}\right] + a_2u_2 \times [Gbest^{i} - R_{k}^{i}] \qquad (2.10)$$

$$R_{k+1}^{i} = R_{k}^{i} + v_{k+1}^{i} \qquad (2.11)$$

Where:

R_{k}^{i}: Position of the i^{th} particle during k^{th} iteration.

v_{k}^{i}: Velocity of the i^{th} particle during k^{th} iteration.

$Pbest_{k}^{i}$: Individual best fitness achieved by a i^{th} particle till k^{th} iteration.

$Gbest_{k}^{i}$: Global best fitness achieved by a i^{th} particle till k^{th} iteration.

w: Inertial coefficient

$\alpha_1 and\ \alpha_2$: Cognitive and social parameters.

$u_1 and\ u_2$: Random numbers between 0 and 1.

Noted that Equation 2.10 is the summation of three different velocities updates parameters. Each parameter has its own role of important in optimizing the PSO algorithm. Here goes the explanation about the parameters:

a) *Inertial component*: For the first term wv_k^i, it is known as an inertia component that is responsible for preserving the original direction of particle (Jawa,2011). Generally, the inertial coefficient w may be chosen between 0.8 and 1.2 (Johansson,1993).
b) *Cognitive component*: The second term $a_1u_1 \times \left[Pbest_k^i - R_k^i\right]$, is called the cognitive component. The cognitive component also can be defined as the memory of the particle, forcing it to move toward the search space that has archived the best individual fitness ($pbest_k^i$) (Blondin 2009). The cognitive coefficient a_1 is chosen close to 2. This coefficient is responsible for the step size, measuring what a particle would take to reach its 'individual best solution' (Jawa,2011).
c) *Social component*: The third term $a_2u_2 \times [Gbest^i - R_k^i]$ is known as the social component. This component is also known as the memory of the particle. This term would force the particle to move toward the search space that has achieved the best global fitness ($gbest^i$) (Blondin,2009). The social coefficient a_2 is also chosen to be close to 2. Unlike the cognitive component, the social component would drive a particle toward the best global candidate solution with a step size of a_2 (Jawa,2011).

Moreover, PSO has several advantages over other similar optimization techniques such as (Valle,2006):

a) PSO is easier to implement and there are fewer parameters to adjust.
b) In PSO, every particle remembers its own previous best value as well as the neighborhood best.
c) PSO is more efficient in maintaining the diversity of the swarm (Kachitvichyanukul,2012) (more similar to the ideal social interaction in a community), since all the particles use the information related to the most successful particle in order to improve themselves.

In PSO, a solution is represented as a particle, and the population of solutions is called a swarm of particles. Each particle moves to a new position using the velocity. Once a new position is reached, the best position of each particle and the best position of the swarm are updated as needed. The velocity of each particle is then adjusted based on the experiences of the particle. The process is shown in Figure 2.7 below (Kohn,1998):

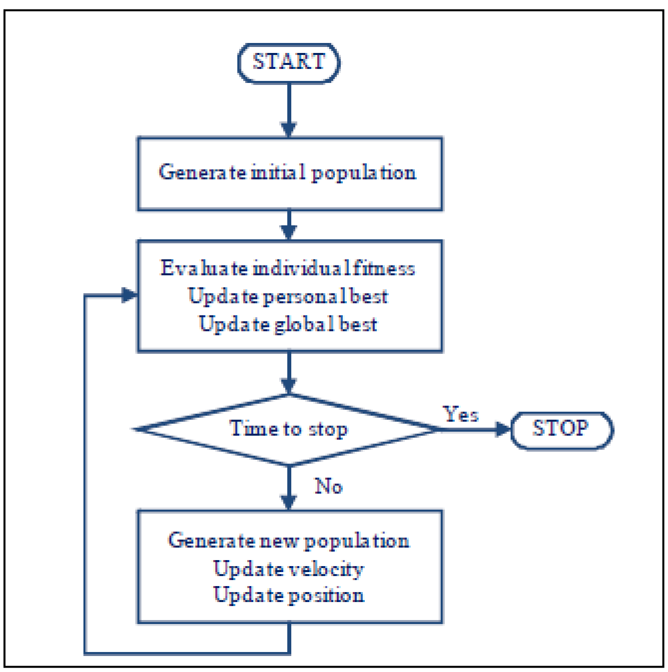

Figure 2.7: Flowchart of Particle Swarm Optimization Algorithm (Kohn,1998)

The first process of PSO is initialization where the initial swarm of particles is generated. Each particle is initialized with random position and velocity. Then, each particle will be evaluated for fitness value. Each time a fitness value is calculated, it is compared against the previous best fitness value of the whole swarm, and the personal best and global best positions are updated where appropriate. If a stopping criterion is not met, the velocity and position are updated to create a new swarm. The personal best and global best positions, as well as the old velocity, are used in the velocity update. The process is repeated until a stopping criterion is met.

2.7 Correlation

Correlation is widely used in digital signal processing because it is easy to understand and implementation. Correlation can be defined as the degree of similarity between two signals. If the two signals are identical, then the correlation coefficient is 1. However, if the both signals are totally different, the correlation coefficient becomes 0 and if both signals are identical but the phase is shifted by exactly 180º (known as mirror), then the correlation coefficient is -1. Correlation can be divided into two which are cross-correlation and autocorrelation. When two independent signals are compared, it is known as cross-correlation and when the same signal is compared to phase shifted copies of itself, it is known as autocorrelation.

2.7.1 Cross-correlation

The cross-correlation is a very useful tool that investigates the degree of association between two signals (Eialli,2004). An important use of the cross-correlation function is in providing measure of similarity between two signals as a function of the delay between them. The cross-correlation between $x(t)$ and $y(t)$ can be described by (Taghizahed,2000):

$$R_{xy}(\tau) = \lim_{T\to\infty} \frac{1}{T} \int_{-T}^{T} x(t)y(t+\tau)dt \quad (2.12)$$

Or

$$R_{yx}(\tau) = \lim_{T\to\infty} \frac{1}{T} \int_{-T}^{T} y(t)x(t+\tau)dt \quad (2.13)$$

Where:

T: The period of observation

$R_{xy}(\tau)$: Always real-valued

The properties of cross-correlation are shows in Table 2.1 below:

Table 2.1: Properties of Cross-correlation function (Taghizahed,2000)

$R_{xy}(m)$ is always a real valued function which may be positive or negative.
$R_{xy}(m)$ may not necessarily have a maximum at m=0 nor $R_{xy}(m)$ an even function.
$R_{xy}(-m) = R_{xy}(m)$

2.7.2 Autocorrelation

The autocorrelation is an operation that involves identical function (Ljung,1998). Autocorrelation may be viewed as a measure as similarity, or coherence, between a function $x(t)$ and it is shifted version. Clearly, under no shift, the two functions match and the result in a maximum for the autocorrelation.

But with increasing shift, it would be natural to expect the similarity and hence the correlation between $x(t)$ and its shifted version decrease. As the shift approaches infinity, all traces of similarity will be vanishing and the autocorrelation decays to zero.

Consider a random process $x(t)$ (continues-time), the autocorrelation function is written as below in equation (2.14) (Taghizahed,2000);

$$R_{xx}(\tau) = \lim_{T\to\infty} \frac{1}{2T} \int_{-T}^{T} x(t)x(t+\tau)dt \qquad (2.14)$$

Where:

T: The period of observation

$R_{xx}(\tau)$: Always real-valued and an even function with a maximum value at τ=0

The properties of autocorrelation are shows in Table 2.2 below:

Table 2.2: Properties of Autocorrelation function (Taghizahed,2000)

Autocorrelation Properties	
Maximum value	The magnitude of the autocorrelation function of a wide sense stationary random process at lag m is upper bounded by its value at lag m=0: $R_{xx}(0) \geq \lvert R_{xx}(k)\rvert fork \neq 0$
Periodicity	If the autocorrelation function of a WSS (Wide Sense Stationary) random process is such that: $R_{xx}(m_0) = R_{xx}(0)$ for some m_0, then $R_{xx}(m)$ is periodic

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