THE SYSTEM IDENTIFICATION OF HVAC USING ARTIFICIAL NEURAL NETWORK

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To my mom, dad and my wonderful supervisor DR. INTAN ZAURAH MAT DARUS who have supported me all the way since the beginning of my studies.

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ABSTRACT

An air conditioner or AC is an apparatus that designed to adjust the temperature as well as humidity in house. A multi-functional air conditioning system which contains functions like heating, ventilation and air conditioning is referred to as “HVAC”. In this study, the purpose is to estimate the dynamic model of the HVAC system by using the Least Square (LS), Recursive Least Square (RLS) and Artificial Neural Network (ANN) techniques. The input and output data used to estimate the dynamic model in this study were obtained experimentally by previous studies. The system identification techniques were conducted based on single-input-single-output (SISO) autoregressive with exogenous (ARX) model structure. The validity of the models was investigated based on mean square error (MSE), regression and correlation tests. The results of every techniques are compared with their performance of identification the system. It is indicating that in this study, the RLS method shows the better results than LS method, however in the methods of system identification using ANN, the time-series structured the method, such as Elman Network give the best results.

ABSTRAK

Penyaman udara atau AC adalah satu radas yang direka untuk melaraskan suhu serta kelembapan di dalam rumah. Sistem penghawa dingin yang mengandungi pelbagai fungsi seperti pemanasan, pengalihudaraan dan penyaman udara disebut sebagai "HVAC". Kajian ini bertujuan untuk menganggarkan model dinamik sistem HVAC dengan menggunakan teknik Least Square (LS), Recursive Least Square (RLS) dan Artificial Neural Network (ANN). Data masukan dan keluaran yang digunakan untuk menganggar model dinamik dalam kajian ini diperolehi secara eksperimen oleh kajian sebelumini. Teknik-teknik mengenalpasti sistem telah dijalankan berdasarkan struktur satu masukan satu keluaran dengan model struktur autograsi dengan eksogen (ARX). Kesahihan model telah disiasat berdasarkan purata ralat kuasa dua (MSE), regresi dan korelasi. Keputusan setiap teknik dibandingkan berdasarkan prestasi mereka untuk mengangkarkn system tersebut. Dalam kajian ini kaedah Recursive Least Square menunjukkan keputusan yang lebih baik daripada kaedah Least Square. Dalam kaedah pengenalan sistem menggunakan ANN, pengangaran mengunakan kaedah, Elman Rangkaian memberikan keputusan yang terbaik.

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LIST OF ABBREVIATIONS

AAC	Automotive Air-Conditioning
AC	Air-Conditioning
ACF	Auto Correlation Function
ANN	Artificial Neural Network
ANFIS	Adaptive Neuro-Fuzzy Inference Systems
ARX	Auto-Regressive Exogenous
ARMA	Auto-Regressive Moving Average Exogenous
ARMAX	Autoregressive–Moving-Average
BP	Backpropagation
CCF	Cross Correlation Function
EA	Evolutionary Approach
EHV	Extra high voltage
HVAC	Heating Ventilation And Air Conditioning
LS	Least Square
MISO	Multi-Input Single-Output
MSE	Mean Square Error
NARMAX	Non-Linear Auto-Regressive Moving Average with Exogeneous Input
RBF	Radial Basis Function
RLS	Recursive Least Square
SISO	Single Input Single Output
SPIM	Single Phase Induction Machine

LIST OF SYMBOLS

$y(t)$	Actual system output at time *t*
$e(t)$	White noise at time *t*
$X(t)$	Time series data
$\emptyset_i$	Parameters of the system
p	Autoregressive terms
q	Moving average terms
η_i	Parameters of input d_t
d_t	External time series
$A(z^{-1})$	polynomials with associated parameters of autoregressive, exogenous and moving average parts
$B(z^{-1})$	polynomials with associated parameters of autoregressive, exogenous and moving average parts
$C(z^{-1})$	polynomials with associated parameters of autoregressive, exogenous and moving average parts
℃	Temperature in degree
N_c	Speed of compressor
V	Velocity
E	MSE
β	LS estimation parameters

a_j(t)	Measurement data
b (t)	Measurement data
S_i	Output of hidden layer of ANN
w_i	Weight
a_i	Input of hidden layer
θ	Bias
z (t-1)	Previous data in hidden layer in Elman
$U(t)$	Input signal of ANN
Y_m	Output function of RBF
Z_j	Output of hidden layers in RBF
$R(s,t)$	Autocorrelation function
μ, σ	Time-dependence
$f * g$	Complex conjugate with functions f and g

CHAPTER 1

INTRODUCTION

1.1 Background Information

Nowadays, air conditioners are commonly used in our lives, especially in the tropical and subtropical regions of world. An air conditioner or AC is an apparatus that designed to adjust the temperature as well as humidity in house. A multi-functional air conditioning system which contains functions like heating, ventilation and air conditioning is referred to as "HVAC" (McQuiston *et al*., 2004). One of the functions of air conditioner is to capture heat in the house and throw it outside. However, changing the temperature is not the only function of air conditioner, but the another feature of air conditioner is dehumidifying. So that HVAC can make people feel more comfortable (Olesen and Brager, 2004).

The air conditioner can be divided into two types: the traditional air conditioner and inverter air conditioner. The principle of traditional AC is controlling the refrigeration compressor in a constant speed, in order to manipulate the temperature in house, while the inverter air conditioner can change the speed of refrigeration compressor with the changing value of grid frequency. There are three basic subsystems included in an air conditioning system: circulating refrigeration system, air circulation system and electrical control system. By manipulation of electrical control system, the other two parts can work appropriately. The system identification

is the art and scientific method which uses statistical methods to build mathematical models of dynamical systems from observed input-output data (Roll and Ljung, 2008).

System identification can be conducted by applying the input and the output signals that has been measured. Using the parametric or non-parametric method in system identification, It is possible to get transfer function of a model for system. Parametric identification methods are types of mathematic methods used to define the transfer functions of systems through parametric models with a finite number of parameters. Non-parametric identification methods (infinite or large number of parameters) are techniques to estimate model behavior without the necessity of using a given mathematical model set. Least Square (LS), Recursive Least Square (RLS) and Neural Network (NN) are usually applied in system identification (Chow and Teeter, 1997).

There were some researchers who have put into effects to explore ways of complement system identification, such as, Teeter and Chow (1997) using functional link neural network on HVAC or the application of operating point dependent parameters-structure on AC unit (Riadi *et al*., 2006). Also, the application of Adaptive Neuro-Fuzzy Inference Systems (ANFIS) on fresh air system has been done by Yang *et al*., (2010).

The fuzzy logic, artificial neural networks, and expert systems methods can be used to do the system identification in HVAC in order to estimate future plant outputs and obtain plant input/output sensitivity information, therefore, Teeter and Chow (1997) have proposed the functional link neural network to do the system identification in the HVAC, This system represents a simplification of an overall building climate control problem, but retains the distinguishing characteristics of an HVAC system.

Beside methods above, there are many other ways to complement the system identification. An online maximum-likelihood based identification algorithm is developed for the air conditioner system. The experimental setup was designed to collect data in order to identify the system parameters. Finally, the result of work has shown that the estimated system it was reliable for the future study (Sami *et al*., 2004).

1.2 Problems Statement

Heating, ventilating, and air-conditioning (HVAC) systems are a permanent part of everyday life in our industrialized society. A mere 1% improvement in energy efficiency of these systems translates into annual savings of millions of dollars at the national level (Teeter and Chow, 1997).

Saudi Arabia summer period presents a high demand of electrical power due to air conditioner (AC) loads. The rapid growth in AC load causes the increasing system peak. In the recent years, worldwide electrical energy crisis has emerged with visible undesirable effects going to complete blackout (Sami *et al*., 2004). In China, energy consumption of heating, ventilating and air conditioning (HVAC) system is approximately from 10% up to 60%. The rate of the energy consumption is high and as to these kinds of issues, optimize and develop the air conditioning system have become more and more important (Guo *et al*., 2005).

The HVAC system is highly non-linear system, which means the input signal and output signal has no proportional relation, in other words, the HVAC system can be difficult to control. However, the HVAC system has played a very important role in modern world, therefore, study the relation between the input signals and output signals in air conditioner, and identify the air conditioner system have significant means.

1.3 Objective

The objective of this research is to model the air conditioning system using system identification techniques and to simulate the system within MATLAB environment.

1.4 Scope of Work

- Data acquisition of an air conditioning system
- Development of system identification techniques using neural networks, Least square and Recursive Least square identification methods for the air conditioning system
- Validation of all the developed models
- Programming and simulation of the system identification of the HVAC

1.5 Research Methodology

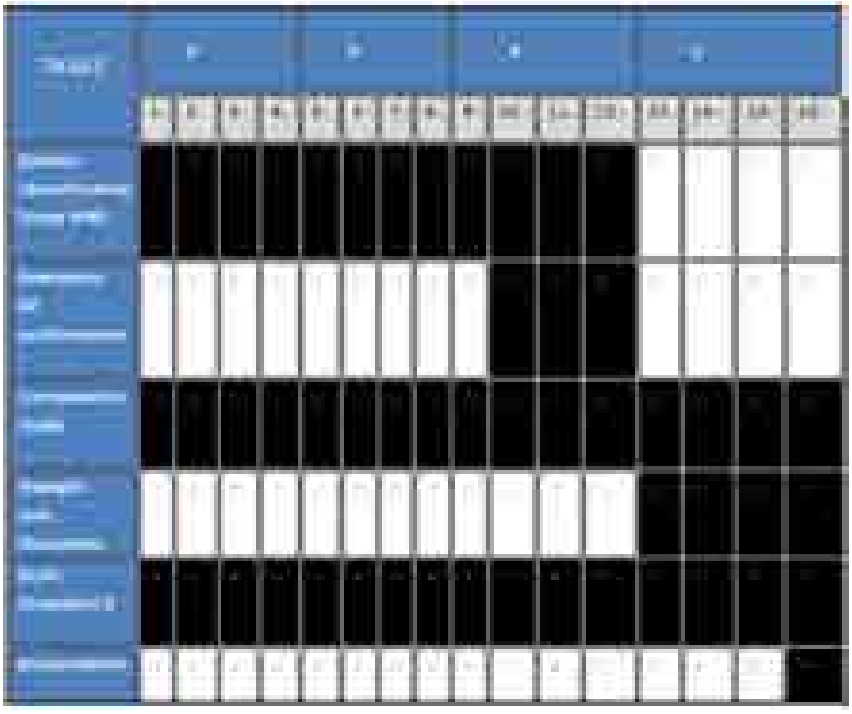
The research involved finding the transfer function of an air conditioning system using system identification method. System identification is a method of obtaining the system's transfer function or some equivalent mathematical description from measurements of the system's input and output. The input and output data are obtained from the air conditioning system. The system identification use Recursive Least Square (RLS) and Neural Networks (NN). The Figure 1.1 shows the steps of the research.

Figure 1.1 Flow Chart of the project

1.6 Gantt Chart

The Gantt chart is given to show the schedule of the study, which contains the steps of studying and the time of conducting the research. The Gantt chart can be seen in Table 1.1.

Table 1.1 Gantt chart of the research



1.7 Outline of Thesis

The thesis was written by dividing it into five chapters; Chapter 1 covers the background of the study including problem statement, objectives, scope of the study, research methodology and outline of the thesis.

The chapter 2 was focusing on the literature review. The literature review contains the basic principle of the HVAC as well as the construction of system, the knowledge of system identification by using least-square, recursive least square and artificial neural network.

In the chapter 3, the methodology was introduced. The model validation has been done after the system identification. And the programs of system identification by coding of MATLAB were designed.

The chapter 4 was mainly describing the results analyzing and comparison, in this chapter, each of the modeling methods were compared, and the best results of methods were displayed.

In Chapter 5, the conclusion of this thesis and suggestion for future work has been given.

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