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INDOOR TEMPERATURE AND HUMIDITY CONTROL USING GENERALIZED PREDICTIVE CONTROL-FUZZY COGNITIVE MAP CONTROLLER ON DIRECT EXPANSION AIR CONDITIONING SYSTEM

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By

FARINAZ BEHROOZ

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

April 2017

Dedicated

TO

My lovely Parents

Azar and Faramarz

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

INDOOR TEMPERATURE AND HUMIDITY CONTROL USING GENERALIZED PREDICTIVE CONTROL-FUZZY COGNITIVE MAP CONTROLLER ON DIRECT EXPANSION AIR CONDITIONING SYSTEM

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April 2017

Chairman : Professor Ir. Norman Mariun, PhD
Faculty : Engineering

Nowadays, the application of different controllers on heating, ventilating and air-conditioning system (HVACs) are considered as an important issue in order to improve the performance of the system, due to the high demand of these appliances in the buildings and their high energy consumptions in the buildings. Direct expansion air conditioning system (DX A/C) is mostly used in the small to medium size buildings in tropical regions. The DX A/C system is nonlinear, Multiple-Input and Multiple-Output (MIMO) and inherently complex system with strong cross coupling effect between supply air temperature and supply air humidity.

The previous researches shows that designing the nonlinear controllers are limited and difficult due to the complexity and uncertainty of the system, and complex mathematical analysis in finding a Lyapunov function. On the other hand, for making the control design easy, the MIMO structure of the system are considered as Single-Input and Single-Output (SISO) system by decoupling the system. In order to consider the coupling effects, MIMO control strategies are required. But, these strategies mostly are applied to the linearized model of the system around operating point and makes the working range of the controller limited to the neighborhood of operating range. For full control of the system, the wider operating range is required.

Therefore, the goals for designing the suitable controller on DX A/C system are designing MIMO nonlinear controller by easy mathematic and structure. The simple Fuzzy Cognitive Map (FCM) control algorithm by using generalized predictive control (GPC) for assigning the weights are used to obtain the goals of comfort and energy saving by considering the real characteristics of air conditioning system.

The performance analysis of the designed controller was tested by set point tracking test and disturbance rejection test. The results for both tests showed that by changing the compressor and supply fan's speed, the proposed controller successfully can be implemented to the DX A/C system. Also, the controller work successfully in wider operating range in other set points (22-26 ^{o}C). The GPC-FCM controller are compared by LQG controller in different conditions and the results shows the better performance of GCP-FCM controller in comparison with LQG one.

The achievements of this research are a new design approach to MIMO nonlinear controller for DX A/C system to stabilize the humidity and temperature of the air conditioned room on desired set points, integration of different control categories in single control scenario by soft computing methodology to response all the requirements of the system, introducing new platform based on the Generalized Predictive Control- Fuzzy Cognitive Map control method for the first time in the literature about HVAC systems, new development in nonlinear control systems with simple mathematics, new solution for approaching to MIMO system with coupling effect without linearization of the model due to a simple structure of FCM, energy saving and energy efficiency by this new control design.

In conclusion, by employing the GPC-FCM controller on the DX A/C system a soft, intelligent, hybrid, nonlinear and MIMO control method is obtained. Decreasing the energy usage of the air conditioning system are achieved by using the variable speed supply fan and variable speed compressor and applying the hybrid GPC-FCM Control design for preventing from losing energy by making the controller errors as least as possible.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

KAWALAN SUHU DAN KELEMBAPAN DALAMAN MENGGUNAKAN PENGAWAL PETA KOGNITIF KAWALAN-KABUR RAMALAN UMUM PADA SISTEM PENGHAWA DINGIN PENGEMBANGAN LANGSUNG

Oleh

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Sekarang ini, permohonan alat-alat kawalan berbeza di memanaskan, menganginkan dan sistem penyaman udara (HVACs) dianggap sebagai satu isu penting supaya memperbaiki prestasi sistem, disebabkan permintaan tinggi alat-alat ini dalam bangunan dan penggunaan tenaga tinggi mereka dalam bangunan. Sistem penghawa dingin pengembangan yang langsung ada kebanyakannya digunakan dalam yang kecil kepada bangunan-bangunan saiz sederhana di kawasan-kawasan tropika. DX A/C sistem tak linear, Multiple-Input dan Multiple-Output dan sistem yang memang kompleks dengan kuat kesan gandingan silang antara suhu udara bekalan dan kelembapan udara bekalan.

Penyelidikan sebelumnya menunjukkan bahawa mereka alat-alat kawalan tak linear dihadkan dan sukar disebabkan kerumitan dan ketakpastian sistem, dan analisis matematik kompleks dalam mencari satu fungsi Lyapunov. Sebaliknya, untuk membuat reka bentuk kawalan mudah, struktur MIMO sistem dianggap sebagai sistem Single-Input dan Single-Output dengan penduaan sistem. Bagi mempertimbangkan kesan-kesan gandingan, strategi mengawal MIMO dikehendaki. Tetapi, strategi-strategi ini kebanyakannya digunakan ke atas model dilinearkan sistem sekitar titik pengendalian dan membuat julat pekerjaan pengawal dihadkan kepada kawasan kejiranan julat operasi. Untuk kawalan penuh sistem, julat operasi lebih luas diperlukan.

Lantarannya, matlamat bagi mereka-bentuk pengawal sesuai di DX A/C sistem mereka MIMO pengawal tak linear oleh matematik mudah dan struktur. Algoritma kawalan Fuzzy Cognitive Map (FCM) mudah dengan menggunakan kawalan (GPC) ramalan am untuk menentukan pemberat digunakan untuk mendapatkan matlamat

keselesaan dan penjimatan tenaga dengan mempertimbangkan ciri-ciri sebenar sistem penghawa dingin.

Analisis prestasi pengawal bercorak telah diuji oleh titik set menjejaki penolakan ujian dan gangguan ujian. Keputusan untuk kedua-dua ujian menunjukkan bahawa dengan mengubah kelajuan pemampat dan membekalkan kipas, cadangan pengawal dengan jayanya boleh dilaksanakan kepada DX A/C sistem. Juga , pengawal kerja dengan jayanya dalam julat operasi lebih luas dalam titik set (22-26 ºC) lain. Pengawal GPC-FCM dibandingkan oleh pengawal LQG dalam syarat-syarat berbeza dan keputusan menunjukkan prestasi lebih baik pengawal GCP-FCM berbanding dengan LQG satu.

Kejayaan penyelidikan ini ialah pendekatan reka bentuk baru kepada MIMO pengawal tak linear untuk DX A/C sistem memantapkan kelembapan dan suhu bilik berhawa dingin di titik set teringin, integrasi kategori-kategori kawalan berbeza dalam tunggal senario kawalan oleh kaedah kiraan mudah kepada sambutan semua keperluan sistem, memperkenalkan platform baru berdasarkan Generalized Predictive kaedah mengawal Fuzzy Cognitive Map Control- buat kali pertama dalam kesusasteraan tentang sistem-sistem HVAC, pembangunan baru dalam sistem kawalan tak linear dengan matematik mudah, penyelesaian baru kerana mendekati kepada sistem MIMO dengan kesan gandingan tanpa pelinearan model disebabkan satu susunan biasa FCM, penjimatan tenaga dan kecekapan tenaga oleh reka bentuk pengaruh baru ini.

Dalam kesimpulan, dengan mengambil pengawal GPC-FCM di DX A/C sistem satu lembut, pintar, hibrid, tak linear dan kaedah mengawal MIMO diperolehi. Menurun penggunaan tenaga sistem penghawa dingin dicapai dengan menggunakan membekalkan kipas laju boleh ubah dan pemampat laju boleh ubah dan menggunakan hibrid reka bentuk GPC-FCM Control bagi mencegah dari kalah tenaga dengan melakukan kesilapan-kesilapan pengawal sebagai paling kurang yang mungkin.

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I certify that a Thesis Examination Committee has met on 20 April 2017 to conduct the final examination of Farinaz Behrooz on her thesis entitled "Indoor Temperature and Humidity Control using Generalized Predictive Control-Fuzzy Cognitive Map Controller on Direct Expansion Air Conditioning System" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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LIST OF ABBREVIATIONS

AHU	Air-handling unit
ANFIS	Adaptive neuro fuzzy inference system
ANN	Artificial Neural Network
BAS	Building automation systems
CPA	Control Performance Assessment
DX A/C	Direct expansion air conditioning
EEV	Electronic expansion valve
EKF	Extended Kalman Filter
EMCS	Energy management control systems
ET	Effective temperature
FBAM	Fuzzy Bidirectional Associative Memories
FCM	Fuzzy Cognitive Map
FL	Fuzzy logic
FLC	Fuzzy logic control
GA	Genetic algorithm
GFS	Genetic Fuzzy System
GPS	Global positioning system
GPC-FCM	Generalized Predictive control- Fuzzy Cognitive Map
HVAC	Heating, ventilating and air-conditioning
HVAC&R	Heating, ventilation, air-conditioning, and refrigeration
IAE	Integral of the absolute magnitude of error
IAQ	Indoor air quality
IB	Intelligent Buildings
ISE	Integral Square Error
ITAE	Integral Time-absolute error
KB	Knowledge base
LMS	Least Mean Square
LQG	Linear Quadratic Gaussian
MF	Membership function
MIMO	Multiple-Input and Multiple-Output
MPC	Model Predictive Control
NN	Neural network

P-E	Pressure- Enthalpy
PID	Proportional–Integral–Derivative
PMV	Predicted Mean Vote
PPD	Predicted Percentage Dissatisfied
PSO	Particle swarm optimization
RB	Rule base
RCGA	Real-coded genetic algorithm
RLS	Recursive least square
RMS	Recursive Mean Square
SISO	Single-Input and Single-Output
SG	Scaling gain
S-norm	T-conorm
STC	Self-Tuning Control
T-E	Temperature-Entropy
T-norms	Triangular norms
VAVAC	Variable Air Volume Air-Conditioning
Z-N	Ziegler-Nichols

LIST OF SYMBOLS

A_1	Air side heat transfer area of evaporator in dry-cooling region [m^2]
A_2	Air side heat transfer area of evaporator in wet-cooling region [m^2]
A_i	Activation degree of each node [DL]
A_i^{new}	Activation value of concept *i* at time t+1 [DL]
A_j^{old}	Activation value of concept *j* at time t [DL]
A_i	State value of nodes connecting with this input node [DL]
A_j	State value of input node *j* [DL]
A_{s1}	Air side cross section area of the evaporator in dry cooling region [m^2]
A_{s2}	Air side cross section area of the evaporator in dry cooling region [m^2]
A, B, C	Coefficient matrices [DL]
c_p	Specific heat [1.005 kJ/kg K]
C_p	Saturated refrigerant specific heat under P_e [kJ/(kg.K)]
d_j	Expected value of input node *j* [DL]
e	Rotor eccentricity [m]
f	Air volumetric flow rate [m^3/hr]
f	Threshold function [DL]
h_{fgh}	Latent heat of vaporization of water [kJ/kg]
h_{re2}	Enthalpy of refrigerant leaving the receiver [kJ/kg]
h_{rc1}	Enthalpy of superheated refrigerant at compressor suction [kJ/kg]
h_{r2}	Enthalpy of the refrigerant leaving the DX evaporator [kJ/kg]
h_f	Saturated liquid enthalpy [kJ/kg]
h_3	Enthalpy of air leaving wet-cooling region of evaporator [kJ/kg]

$h_{r,sa}$	Enthalpy of saturated refrigerant vapour at evaporating pressure [kJ/kg]
h_{rc}	Enthalpy of superheated refrigerant at compressor suction [kJ/kg]
h_{r34}	Enthalpy of the refrigerant exiting the receiver [kJ/kg]
J	Performance index [DL]
$je1$	Colburn factors [DL]
$je2$	Colburn factors [DL]
K	Iteration step [DL]
K1	Optimal gain matrix [DL]
K_a	Optimal feedback gain matrix with integrator [DL]
K_2	Gain matrix [DL]
L	Lower triangular matrix [DL]
L	Kalman filter gain matrix [DL]
l	Stroke of cylinder [m]
L_1	length of the dry cooling region on the air side of evaporator [m]
L2	Length of the dry cooling region on the air side of evaporator [m]
M	Moisture load generation in the conditioned space [kg/s]
m_{r6}	Mass flow rate of the refrigerant exiting from the evaporator [kg/s]
m_{r1}	Mass flow rate of sucked in by the compressor [kg/s]
m_{r2}	Mass flow rate leaving the compressor [kg/s]
m_{rs}, m_{r3}	Mass balance on zone Vcr1[kg/s]
p	Pressure [Pa]
Pr	Prandtl number [DL]
P_c	Condensing pressure [Pa]
P_e	Evaporating pressure [Pa]

Q_{load}	Space sensible load [kW]
Q_{spl}	Heat gain of the supply fan [kW]
$Q_{sensible}$	Sensible heat flow [kW]
Q_{latent}	Latent heat flow [kW]
R22	Refrigerant 22
r	Radius of rotor [m]
R	Radius of cylinder [m]
s	Compressor speed [rpm]
SH	Degree of superheat [^{o}C]
T	Temperature [^{o}C]
T_1	Temperature of the air which leaving the DX cooling coil [^{o}C]
T_2	Temperature of the air conditioned room [^{o}C]
T_3	Temperature at the ending of the dry-cooling region [^{o}C]
T_w	Temperature of the evaporator wall [^{o}C]
T_n	Neutral temperature [^{o}C]
T_m	Outside mean dry bulb temperature [^{o}C]
$T_{r,sa}$	Temperature of saturated refrigerant vapour under P_e [^{o}C]
T_{sup}	Superheat vapour refrigerant temperature [^{o}C]
U	Control inputs [DL]
u^0	Input vector [DL]
U	Upper triangular matrix [DL]
u	feedback control law [DL]
V	Volume of the conditioned space [m^3]
Vcr1	Desuperheating region [DL]
Vcr2	Vapor zone of two phase region [DL]

Vcr3	Liquid zone of two phase region [DL]
Vcr4	Sub cooling region [DL]
V_{h1}	Air side volume of evaporator in dry-cooling region [m^3]
V_{h2}	Air side volume of evaporator in wet-cooling region [m^3]
V_{com}	Swept volume of the rotor compressor [m^3]
v	Air velocity [m/s]
v_s	Specific volume of superheated refrigerant [m^3/kg]
W_1	Moisture content of the air which leaving the DX cooling coil [kg/Kg]
W_2	Humidity of the air conditioned room [kg/Kg]
W_{ij}	Effect of nodes to each other [DL]
X	State variables [DL]
x^0	State vector [DL]
y	Output variables [DL]
ρ	Density [kg/m^3]
α1	Convective heat transfer coefficients of evaporator airside in dry-cooling region [kW/(m^2.K)]
α2	Convective heat transfer coefficients of evaporator airside in wet-cooling region [kW/(m^2.K)]
β	Compression index [DL]
ρ	Air density at standard conditions [1.202 kg/m^3]
λ	Compressor displacement coefficient [DL]
η	Learning rate [DL]
ε	Rotor relative eccentricity [DL]
λ_{sys}	Eigenvalue [DL]
$\dot{\eta}$	Integrator variable [DL]

Δt	Temperature difference [^{o}C]
Δw	Humidity ratio difference [kg/Kg]

Note: DL = Dimensionless

CHAPTER 1

INTRODUCTION

1.1 Introduction and background

The heating, ventilating and air-conditioning or simply HVAC system is the more energy consuming part of the building automation systems (BAS) in Intelligent Buildings (IBs). As a result of the limited sources of energy in the world and worsen by fuel crisis, designing improved controllers to save energy and energy efficiency is more significant challenge for control engineers (Tachwali et al., 2007). By reason of the critical influence of HVACs systems on energy and power consumption, it is significant to being familiar with the operation as well as the structure of HVAC systems (Tashtoush et al., 2005).

As a part of HVAC system, the air conditioning system could be considered as the direct expansion air conditioning (DX A/C) system. The mentioned system has two types, window units and split units which they are commonly employed in small to medium size buildings by reason of their advantages like (Qi and Deng, 2008):

1. simple configuration,
2. a higher energy efficiency, and
3. low cost to own and maintenance.

According to Tashtoush et al. (2005), energy efficiency and indoor climate conditions are most important goals of designing HVAC systems. As a consequence of complicated features of an HVAC system like coupling effect in air conditioning part, attaining to the mathematical model of HVAC system is very difficult (Tashtoush et al., 2005) and as well designing the appropriate controller turn into a big challenge (Wang et al., 2006,Lei et al., 2006).

As the DX A/C system is a MIMO system with coupling effect between temperature and humidity, a single control scenario is required that considered these two parameters and their cross-coupling effect simultaneously (Qi and Deng, 2008). Also, this system is complex and nonlinear; therefore reaching the accurate mathematical model is difficult. Then the nonlinear control algorithm is required.

From the energy saving point of view, the intelligent control method is required to adjust the parameters according to the needs of the system at that time with learning ability to prevent the energy lost and balance between thermal comfort and energy usage.

From optimization point of view, the inherently simple control algorithm is required to replace the optimal control due to their complexity. The hybrid methods performs better than the pure methods. The hybrid methods of more than one soft control methods are applied to increase the accuracy, robustness, on-line learning ability, and easy implementation (Naidu and Rieger, 2011).

Designing the suitable controller based on hybrid methods could save a considerable amount of energy. However, designing a suitable controller to the DX A/C system as a nonlinear, inherently complex and MIMO system with coupling effect on temperature and humidity remains as a big challenge (Huang et al., 2006).

According to Lu et al. (2005), due to the high energy consumption of HVAC system, small increase in system operating efficiency can result in significant energy savings. Therefore, many researches have been done in HVAC control and optimization areas. Referring to Naidu and Rieger (2011), briefly, the recent results on the topic of the different control techniques for HVAC systems are categorized as hard control, soft control, and hybrid control.

1.2 Problem Statement

On the basis of the literature review in the case of DX A/C system, the problems are as follows.

1. Difficult and complex mathematical analysis for designing nonlinear controllers, due to the nonlinearity of the system.
2. In order to mimic the real condition to make the designed system practically applicable, need to keep the MIMO structure of the system and considering the coupling effect of parameters.
3. In order to work in wide operating range, need to keep the nonlinear feature of the system.
4. High energy consumption of the system.

1.3 Hypothesis and justification

The hypothesis is to find a single control scenario with simple mathematics and easy implementation to control the MIMO nonlinear system of DX A/C that is to stabilize the temperature and humidity simultaneously. Another concern of this research is to mimic the reality as close as possible in order for the designed system to be practically applicable. DX A/C system is a MIMO system. Although one can utilize SISO control systems, to control each parameter separately, by decoupling the effects of control variables, yet it degrades the performance of the system (Mirinejad et al., 2008).

In other words, the hypothesis are:

1. A single control scenario with simple mathematics and easy implementation design by considering the nonlinearity, MIMO structure and coupling effect, it will control the MIMO nonlinear system of DX A/C.
2. Compressor and supply fan work simultaneously, the temperature and humidity of the air conditioned room will stabilize at desired set points.
3. Mimic the reality as close as possible, the designed system will be practically applicable.

To solve the aforementioned problem and improve the performance of the system MIMO model have been used. However, based on the literature, MIMO control systems have been applied to linearized model of the systems. It means that the controller is able to stabilize the system around a certain operating point and stability of the system is not guaranteed if the changes are too big (Venkatesh and Sundaram, 2012).

Therefore, nonlinear control techniques are introduced to the DX A/C systems. However, due to complexity and uncertainty of the system, application of nonlinear control techniques to the system is limited. Complex mathematical analysis, stability analysis and dependence to the whole set of states are among the reason that hinder the use of nonlinear control (Gruber and Balemi, 2010). Lyapunov stability theory, feedback linearization and adaptive control are some of the approaches that have been applied to the system (Afram and Jenabi-Sharifi, 2014).

Considering the above mentioned challenges, a simple control method that can deal with the complexity of the system and, at the same time, can be practically feasible is of interest. Fuzzy Cognitive Map is a technique that can meet the needs for this purpose. According to the structure of the FCM, designing a single control scenario by considering the characteristics of the system would be possible. The inputs and outputs of the system with other effective parameters in the process like actuators could be considered as concepts (Stylios and Groumpos, 2000). There are links between concepts which represent the effect of one concept over others (Aguilar, 2005). The MIMO characteristic is considered. It also means that the coupling effects between control variables are taken into account. Moreover, the algorithm and its mathematics are simple and the control signals are applied to the nonlinear dynamic model of the system. As a result, the nonlinear MIMO controller with simple mathematics and algorithm is designed based on soft computing method of FCM.

1.4 Research Objectives

The aim of this research is applying the nonlinear MIMO controller on direct expansion air conditioning system. Thus, the most important goals of this research are as follows.

1. Designing a hybrid, non-linear, intelligent, robust controller with simple algorithm.
2. Performance analysis test of proposed controller by set point tracking and disturbance rejection.
3. Controller performance analysis by working of the controller in wider operating range in different initial set points.
4. Comparison the GPC-FCM controller with LQG controller in different conditions.

1.5 Research Scope

As it is revealed, the purpose of this research should be applying the hybrid Generalized Predictive control- Fuzzy Cognitive Map (GPC-FCM) as a soft control method to control the typical DX A/C system. Reconstructing of mentioned DX A/C system by MATLAB software is based on Qi and Deng (2008) works. The mentioned model was validated by comparing the model simulation results with the experimental results. Therefore, the model is valid and it is useful for designing the MIMO controller. In this research, the GPC-FCM controller is also programmed by MATLAB.

The system is working on Malaysia weather condition. The initial temperature is considered 30 ^{o}C which is the average temperature in Malaysia and 80% for humidity which is average humidity in Malaysia. The desired set points for indoor temperature and humidity are 25 ^{o}C and 50% respectively.

The dimensions of the air conditioned room are 6.8 m (L) × 3.9 m (W) × 2.9 m (H). The model of the DX A/C system which is used in this thesis is based on the information reported by Qi (2009) work. The information was reported by Qi (2009) is based on experimental DX A/C system which is available in the HVAC Laboratory of Department of Building Services Engineering in the Hong Kong Polytechnic University. The experimental DX A/C system consist of:

1. variable speed compressor (Model: HITACHI THS20MC6-Y, Allowable frequency range: 15~ 110 HZ, Rated capacity: 9900 W at 90 HZ, Displacement: 3.04 ml/rev)
2. variable speed supply fan (Model: KRUGER BSB 31, Nominal flow rate: 1700 m^3/h (0.47 m^3/s), Total pressure head: 1100 Pa)
3. electronic expansion valve

4. computerized data measuring (Data acquisition unit, Model: AGLIENT 34970A/34902A; platinum Resistance Temperature Device type, Model: CHINO Pt100/0ºC-3W,Class A, SUS ϕ 3.2-150L; Pressure transmitters, Model: SETRA C206; Barometer, Model: VAISALA PTB-101B; Air flow rate measuring apparatus (FRMA), Model: ROSEMOUNT 3051; Hot-film anemometer, Model: EE70-VT62B5; Pulse-width-modulation (PWM), Model: EVERFINE PF9833; Coriolis mass flow meter, Model: KROHNE MFM1081K+F; Manometer, Model: ROSEMOUNT 3051)
5. LabVIEW logging and control system (PI controllers, Model: YOKOGAWA UT350-1)

Tolerance of air conditioned room temperature (T) is ± 0.7 ºC and tolerance of air conditioned humidity (W) is ± 0.000198 kg/Kg.

1.6 Research Contribution

The contributions of this research are as below:

1. Decreasing the energy usage of the air conditioning system as a part of HVAC system in building automation systems (BASs) by applying the new, novel controller based on the combination of some soft control methods.
2. Employing the GPC-FCM controller as a soft, intelligent control method on DX A/C system to achieve a hybrid nonlinear robust control method on the system.
3. Obtaining a real-time, closed-loop controller with the ability of on-line learning by simple control algorithm which has fast convergence due to utilizing efficient learning ability on applied controller on DX A/C structure.
4. Obtaining the desired air humidity and air temperature of the air-conditioned space by considering the coupling effect of humidity and temperature from the evaporator simultaneously.

1.7 Thesis layout

This thesis is presented in five chapters. The outlines are as follows:

Chapter 1 provides introduction and background information about HVAC and DX A/C systems, BAS and intelligent buildings. The main problem statement, hypothesis and justification, objectives, scopes and contributions are also included in this chapter.

Chapter 2 reviews the HVAC and A/C systems. Then, the different control approaches that have been applied on HVACs and A/Cs, their advantages and disadvantages are included in this chapter. Then, the FCM method are introduced, with the reasons for choosing, improvements in compare with previous methods, significance of FCM method in developing the nonlinear control algorithms. At the end of this chapter, the thermal comfort in hot and humid areas and research background and refrigeration cycle are investigated.

Chapter 3 provides information of the research methodology. The overview on methodology, choosing a proper model of the system, open loop response of the DX A/C system, and choosing the required parameters from the system in order to design a controller are explained in this chapter. The designed FCM controller is presented and also the application of GPC method for assigning the initial weights and supervised learning strategy on proposed FCM controller are investigated. At the end of this chapter the stability analysis of FCM controller, performance analysis tests and performance criteria by performance indexes are explained.

Chapter 4 includes the obtained results using proposed controller in Chapter 3. The set ups that have been used for simulation is mentioned. First, the open loop response of the DX A/C system are simulated and compared with Qi (2009) works. Then, the performance of the GPC-FCM controller is discussed separately. Next, the performance analysis of the controllers is carried out to summarize the performance and robustness of the proposed controller. At last, the GPC-FCM controller is compared with LQG controller in different conditions. This chapter is ended up by discussion and summary.

Chapter 5 conclude this thesis and introduces the potential areas of the future researches.

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LIST OF PUBLICATIONS

Farinaz Behrooz, Norman Bin Mariun, Mohammad Hamiruce Marhaban, Abdul Rahman Ramli, Mohd Amran Mohd Radzi, “New design Approach to MIMO Nonlinear Controller for Direct Expansion Air Conditioning System in Building Automation System”, IEEE 15th. International conference on environment and electrical engineering, June 10-13, 2015, Rome, Publishing in proceedings.

Farinaz Behrooz, Norman Bin Mariun, Mohammad Hamiruce Marhaban, Abdul Rahman Ramli, Mohd Amran Mohd Radzi, “A Design of a Hybrid Non-linear Control Algorithm”, Energies, November 10, 2017.

Farinaz Behrooz, Norman Bin Mariun, Mohammad Hamiruce Marhaban, Abdul Rahman Ramli, Mohd Amran Mohd Radzi, “Review of Control Techniques for HVAC Systems— Nonlinearity Approaches Based on Fuzzy Cognitive Maps”, Energies, Accepted January 9, 2018.

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