UNIVERSITI PUTRA MALAYSIA

DESIGN OF INTELLIGENT CONTROL SYSTEM AND ITS APPLICATION ON FABRICATED CONVEYOR BELT GRAIN DRYER

OMAR F. LUTFY

DESIGN OF INTELLIGENT CONTROL SYSTEM AND ITS APPLICATION ON FABRICATED CONVEYOR BELT GRAIN DRYER

By

OMAR F. LUTFY

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

May 2011

DEDICATION

To my big family

My dear Parents, my Brother, and my Sisters

To my small family

My Wife and my two Daughters, Lana and Leyan

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

DESIGN OF INTELLIGENT CONTROL SYSTEM AND ITS APPLICATION ON FABRICATED CONVEYOR BELT GRAIN DRYER

By

OMAR F. LUTFY

May 2011

Chairman: Associate Professor Samsul Bahari Bin Mohd Noor, PhD

Faculty: Engineering

The grain drying process is one of the most critical post-harvest operations in modern agricultural production. Efficient control of this process is an indispensable requirement especially in light of recent demands for handling latest increase in energy costs, achieving current requirement for eco-friendly technologies, and producing products of high quality.

The grain drying process is characterized by its complex nature. As a result, the mathematical models developed for these systems consist of sets of highly complex and nonlinear partial differential equations (PDEs) which require highly complicated numerical techniques to solve them. Therefore, these models are not suitable for control system design. Moreover, despite the complexity of the drying process, grain dryers, in

particular conveyor-belt grain dryers, are still controlled by conventional PID controllers.

The major objective of this research is to improve the performance of conveyor-belt grain dryers by designing an intelligent control system utilizing the capabilities of the adaptive neuro-fuzzy inference system (ANFIS) to model and control the drying process. To achieve this objective, a laboratory-scale conveyor-belt grain dryer was specifically fabricated for this study.

As the main controller in this work, a simplified ANFIS structure is proposed to act as a proportional-integral-derivative (PID)-like feedback controller to control nonlinear systems. This controller has several advantages over its conventional ANFIS counterpart, particularly the reduction in processing time. Moreover, three evolutionary algorithms (EAs), in particular a real-coded genetic algorithm (GA), a particle swarm optimization (PSO), and a global-best harmony search (GHS), were separately used to train the proposed controller and to determine its scaling factors. These EAs overcome a common problem encountered in derivative-based learning methods, which is the necessity for the teaching signal when applying the ANIFIS as a controller.

To demonstrate the effectiveness of the proposed controller, several non-linear plant models were used to evaluate its performance in terms of control accuracy, generalization ability, and robustness against external disturbances and parameter variations in the controlled system. In addition, several comparative studies were conducted with other related controllers, namely a conventional ANFIS controller, a

variation of the ANFIS network called complex fuzzy basis function network (CFBFN), and a conventional PID controller. Furthermore, the ability of the simplified ANFIS controller to control nonlinear multi-input multi-output (MIMO) systems was also investigated. The results of all these tests clearly indicated the notable performance of the proposed controller.

After fabricating the conveyor-belt grain dryer, a real-time experiment was conducted to dry paddy grains, in particular the MR 219 rice variety. The grains were first re-wetted to a moisture content (MC) of about 18% wet basis (wb). Next, by fixing the dryer operating conditions of temperature, flow rate, and humidity of the drying air, the voltage to the dryer motor was manipulated in a pre-specified sequence to give the required conveyor-belt speed for each paddy sample. The corresponding MC of each of these samples was measured by the XM 120 Moisture Analyzer. The result was a set of 50 input-output samples which were then presented to an ANFIS network to develop the desired process model. The modeling performance achieved by this ANFIS model was then compared with those of an autoregressive with exogenous input (ARX) model and an artificial neural network (ANN) model, and the results clearly showed the superiority of the developed ANFIS model. The simplified ANFIS controller was then applied to control the developed ANFIS-based dryer model using different initial conditions based on real data. In addition, five robustness tests were made to evaluate the controller ability in handling unexpected changes in the drying operating conditions. Furthermore, a comparative study with a genetically-tuned PID controller was conducted. From all these tests, the simplified ANFIS controller has proved its remarkable ability in controlling the grain drying process represented by the developed ANFIS model.

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

REKA BENTUK SISTEM KAWALAN PINTAR DAN APLIKASINYA KE ATAS PENGERING BIJIRIN JENIS PENYAMPAI TALI SAWAT

Oleh

OMAR F. LUTFY

Mei 2011

Pengerusi: Profesor Madya Samsul Bahari Bin Mohd Noor, PhD

Fakulty: Kejuruteraan

Proses pengeringan bijirin adalah salah satu aktiviti yang sangat kritikal di dalam operasi lepas tuai di dalam pertanian moden. Kawalan yang cekap di dalam proses ini adalah sangat perlu terutama dalam menangani permintaan masakini di mana terdapat peningkatan di dalam kos tenaga, mesra alam, dan dalam masa yang sama menghasilkan produk yang berkualiti tinggi.

Proses pengeringan bijirin dikategorikan sebagai kompleks. Disebabkan itu, model matematik yang dibina untuk sistem ini mengandungi set persamaan perbezaan separa yang sangat kompleks dan tak linear yang mana ia memerlukan teknik berangka yang rumit untuk menyelesaikannya. Oleh itu, model-model ini tidak sesuai untuk tujuan sistem kawalan. Walaupun proses pengeringan ini rumit, pengering bijirin terutamanya jenis penyampai tali sawat masih boleh dikawal oleh alat kawalan PID.

Objektif utama penyelidikan ini ialah untuk memperbaiki prestasi alat pengering bijirin jenis penyampai tali sawat dengan membina sistem kawalan yang bijak, menggunakan keupayaan "*neuro-fuzzy inference system (ANFIS)*" untuk model dan mengawal prosess pengeringan. Untuk mencapai objektif ini, pengering bijirin bersaiz kecil untuk kegunaan dalam makmal telah diperbuat khusus untuk penyelidikan ini.

Sebagai alat kawalan utama di dalam penyelidikan ini, struktur ANFIS yang ringkas dicadangkan agar berfungsi seperti alat kawalan PID di dalam litar berbalik untuk mengawal sistem yang tidak lelurus. Alat kawalan ini mempunyai beberapa kebaikan berbanding ANFIS yang biasa, terutamanya dari segi pengurangan masa untuk proses. Tambahan pula tiga algoritma evolusioner atau "*evolutionary algorithma (EA)*", terutamanya algoritma yang dipanggil "*real coded genetic*", "*particle swarm optimization (PSO)*", dan "*global best harmony search (GHS)*" telah digunakan secara berasingan untuk melatih alat kawalan yang dicadangkan dan untuk mendapatkan faktor skalarnya. Kesemua EA ini mengatasi masalah yang biasa dihadapi di dalam kaedah pembelajaran yang menggunakan "*derivative based*", yang mana adalah menjadi keperluan kepada isyarat pengajar apabila menggunakan ANFIS sebagai alat kawalan.

Untuk menunjukkan keberkesanan alat kawalan yang dicadangkan, beberapa model yang tidak lelurus telah digunakan untuk menguji prestasi dari segi ketepatan kawalan, kebolehan membuat kesimpulan menyeluruh, dan ketegapan serta ketahanan terhadap gangguan luar dan variasi pembolehubah di dalam sistem kawalan. Dalam masa yang sama, beberapa perbandingan dibuat di antara alat kawalan seperti ANFIS biasa, variasi ANFIS yang dipanggil "*complex fuzzy basis function network (CFBFN)*", dan PID biasa.

Kebolehan alat kawalan ini untuk mengawal sistem "*multiple input multiple output (MIMO)*" yang tak linear juga diselidiki. Keputusan daripada ujian-ujian ini jelas menunjukkan prestasi yang lebih baik oleh alat kawalan yang dicadangkan.

Setelah pengering padi jenis penyampai tali sawat diperbuat, satu eksperimen telah dijalankan untuk mengeringkan bijirin padi terutamanya baka beras MR219. Bijirin-bijirin tersebut dibasahkan terlebih dahulu sehingga mencapai kandungan kelembapan (MC) menghampiri 18% kadar kelembapan (wb). Kemudian, dengan menetapkan keadaan operasi pengering untuk suhu, laju aliran dan kelembapan udara kering, voltan motor pengering dimanipulasi dengan urutan pra-khusus untuk mendapatkan kelajuan penyampai tali sawat yang dikehendaki bagi setiap sampel padi. MC yang berpadanan untuk setiap sampel telah ditentukan dengan menggunakan XM120 Alat Analisa Kelembapan. Hasilnya ialah 50 input-output sampel yang kemudiannya dihantar ke rangkaian ANFIS untuk membina model proses yang dikehendaki. Prestasi pemodelan yang tercapai oleh model ANFIS ini kemudiannya dibandingkan dengan model autoregresif berinput eksogen (ARX) dan model jaringan saraf tiruan (ANN), dan hasil kajian jelas menunjukkan kelebihan model ANFIS. Alat kawalan ANFIS mudah kemudiannya diaplikasikan untuk mengawal model ANFIS menggunakan kondisi awal berbeza berdasarkan maklumat awal. Selain itu, lima ujian ketahanan telah dijalankan untuk menilai alat kawalan dalam mengawal sebarang perubahan tidak terjangka semasa proses pengeringan. Selanjutnya, satu kajian perbandingan dengan alat kawalan PID yang dilaraskan menggunakan genetik telah dijalankan. Kesemua ujian ini telah menunjukkan bahawa alat kawalan ANFIS mudah terbukti mempunyai kelebihan dalam mengawal alat pengering bijirin yang diwakilkan oleh model ANFIS.

ACKNOWLEDGEMENTS

In the name of Allah, the Most Merciful, the Most Beneficent,

I would like to express my deep appreciation and utmost gratitude to my supervisor Dr. Samsul Bahari Bin Mohd Noor for his guidance, patience, encouragement, and constructive notes throughout the work. His valuable comments and instructions profoundly influenced the quality of this work.

Sincere appreciation is extended to my co-supervisor Associate Professor Dr. Mohammad Hamiruce Marhaban for his precious comments and support during the course of the study. My deep appreciation and thanks go also to my co-supervisor Associate Professor Dr. Kassim Ali Abbas for his valuable comments, generous help, and encouragement. He has been a great teacher and brother. My great thanks are also due to Dr. Ab. Rahim Bin Muda, the Deputy Director of the Rice and Industrial Crops Research Centre at MARDI Headquarters, for his interest in the work and for all the constructive information and comments. His generous help will always be gratefully remembered. I would like also to thank all staff members of the Electrical and Electronics Engineering Department.

My special thanks and gratitude are due to my great parents for their morale support and encouragement. Finally, I would like to thank my wife for her continued patience and support without which I would not have been able to complete this research.

I certify that a Thesis Examination Committee has met on _____ to conduct the final examination of **Omar F. Lutfy** on his thesis entitled "**Design of an Intelligent Control System and its Application on a Fabricated Conveyor-belt Grain Dryer**" 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.

Members of the Thesis Examination Committee were as follows:

Chairman, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Examiner 1, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Examiner 2, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

External Examiner, PhD
Professor
Faculty of _____
University _____
(External Examiner)

_____
BUJANG KIM HUAT, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Samsul Bahari Bin Mohd Noor, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Mohammad Hamiruce Marhaban, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Kassim Ali Abbas, PhD
Associate Professor
Faculty of Food Science and Technology
Universiti Putra Malaysia
(Member)

HASANAH MOHD GHAZALI, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

DECLARATION

I declare that the thesis is my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

OMAR F. LUTFY

Date: 19-May-2011

TABLE OF CONTENTS

		Page
DEDICATION		ii
ABSTRACT		iii
ABSTRAK		vi
ACKNOWLEDGEMENTS		ix
APPROVAL		x
DECLARATION		xii
LIST OF TABLES		xvi
LIST OF FIGURES		xvii
LIST OF ABBREVIATIONS AND NOTATIONS		xxi
CHAPTER		
1	**INTRODUCTION**	1.1
1.1	Background	1.1
1.2	Rough Rice Drying	1.3
1.3	Grain Drying Process Control	1.4
1.4	Application of Soft Computing Techniques in Control System Design	1.5
1.5	Problem Statement	1.7
1.6	Research Objectives	1.9
1.7	Contribution	1.10
1.8	Scope of the Work	1.11
1.9	Thesis Organization	1.11
2	**LITERATURE SURVEY**	2.1
2.1	Introduction	2.1
2.2	Classification of Grain Drying Systems	2.1
2.3	Drying Parameters in Rough Rice Drying Process	2.5
2.3.1	Physical Properties of Rough Rice	2.5
2.3.2	Principles of Rough Rice Drying	2.7
2.3.3	Effects of Drying on the Quality of Rough Rice	2.10
2.4	Rough Rice Drying in Malaysia	2.10
2.5	Models of Grain Drying Systems in Control System Design	2.13
2.6	Control of Grain Drying Systems	2.15
2.6.1	Control of Column-type Cross-flow Grain Dryers	2.16
2.6.2	Control of Conveyor-belt Grain Dryers	2.22
2.7	Fuzzy Logic and Fuzzy Inference Systems	2.25
2.8	Adaptive Neuro-Fuzzy Inference System	2.29
2.8.1	ANFIS Structure	2.30
2.8.2	ANFIS Training Method	2.33

2.9 ANFIS Modeling 2.35
2.9.1 Structure Identification 2.36
2.9.2 Parameter Optimization 2.47
2.10 Application of the ANFIS Network in Control System Design 2.53
2.11 Summary 2.57

3 **DESIGN AND METHODOLOGIES** 3.1
3.1 Introduction 3.1
3.2 Structures of the ANFIS-based Controllers 3.2
3.2.1 Structure of the Conventional PID-like ANFIS Controller 3.2
3.2.2 Structure of the Simplified PID-like ANFIS Controller 3.8
3.2.3 Structure of the CFBFN Controller 3.10
3.3 Parameter Optimization 3.13
3.3.1 Genetic Algorithms 3.13
3.3.2 Particle Swarm Optimization 3.22
3.3.3 Harmony Search Algorithm 3.28
3.4 Conveyor-belt Grain Dryer 3.36
3.4.1 Experimental Setup 3.36
3.4.2 Re-wetting of the Rough Rice 3.39
3.4.3 Moisture Content Measurement 3.42
3.4.4 Training Data 3.43
3.4.5 Data Collection Experiment 3.45
3.4.6 Sampling Method 3.47
3.4.7 Effects of the Drying Parameters 3.48
3.5 Identification of Nonlinear Systems 3.49
3.6 System Identification Based on ANFIS 3.54
3.6.1 Selecting the Input Variables for the ANFIS Model 3.55
3.6.2 Structure Identification for the ANFIS Model 3.58
3.6.3 Parameter Optimization for the ANFIS Model 3.59
3.7 Other System Identification Techniques 3.60
3.7.1 The ARX Model 3.60
3.7.2 The ANN Model 3.61
3.8 Summary 3.65

4 **EVALUATION RESULTS OF THE SIMPLIFIED PID-LIKE ANFIS CONTROLLER** 4.1
4.1 Introduction 4.1
4.2 Simulation Results 4.2
4.2.1 Robustness Tests 4.18
4.2.2 Generalization Tests 4.25
4.2.3 A Comparative Study with the Conventional ANFIS Controller 4.28
4.2.4 A Comparative Study with the CFBFN Controller 4.32
4.2.5 A Comparative Study with the Conventional PID 4.34

Controller
4.3 Control of Nonlinear MIMO Systems 4.36
4.4 Parameter Optimization 4.48
4.5 Summary 4.52

5 **MODELING AND CONTROL RESULTS OF THE CONVEYOR-BELT GRAIN DRYER** 5.1
5.1 Introduction 5.1
5.2 Modeling of the Conveyor-belt Grain Dryer 5.2
5.3 A Comparative Study with Other System Identification Techniques 5.6
5.3.1 The ARX Model 5.7
5.3.2 The ANN Model 5.8
5.4 Control of the Conveyor-belt Grain Dryer 5.11
5.4.1 The Simplified PID-like ANFIS Controller 5.12
5.4.2 The Conventional PID Controller 5.28
5.5 An Alternative Modeling Scenario 5.33
5.6 Summary 5.46

6 **CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK** 6.1
6.1 Conclusions 6.1
6.2 Suggestions for Future Work 6.8

REFERENCES R.1
APPENDICES A.1
BIODATA OF STUDENT B.1
LIST OF PUBLICATIONS L.1