



ALEXANDRIA UNIVERSITY
FACULTY OF ENGINEERING
DEPARTMENT OF COMPUTER SCIENCE AND AUTOMATIC
CONTROL

**TWO NOVEL FUZZY KNOWLEDGE ACQUISITION
TECHNIQUES**

A THESIS
SUBMITTED IN PARTIAL FULFILLMENT FOR
THE DEGREE OF
MASTER OF SCIENCE

BY

Hesham Farouk Abdel Kader Anan

B.Sc., Faculty of Engineering, Alexandria University 1993.

Supervised By

Prof. Dr. Mohamed S. Abougabal

Department of Computer Science and Automatic Control
Faculty of Engineering, Alexandria University

Associate Prof. Dr. Ahmed El Nahas

Department of Computer Science and Automatic Control
Faculty of Engineering, Alexandria University

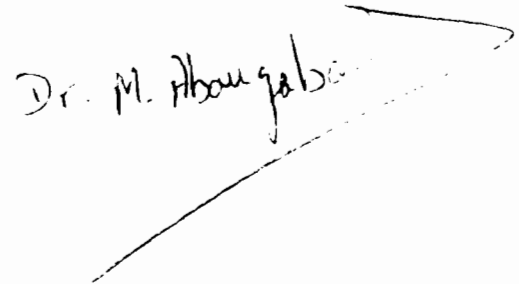
December 1997

We certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science.

Exam Committee:

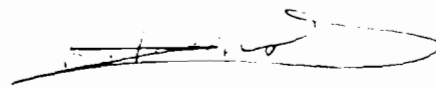
1. Prof. Dr. Mohamed S. Abougabal

*Dept. of Computer Science and Automatic Control,
Alexandria University.*



2. Prof. Dr. Ahmed A. El-Nahas

*Dept. of Computer Science and Automatic Control,
Alexandria University.*



3. Prof. Dr. Amin Shoukry

*Dept. of Computer Science and Automatic Control,
Alexandria University.*



4. Prof. Dr. Saleh A. El-Shehaby

*Medical Research Institute,
Alexandria University.*



For the faculty council:

Prof. Dr. Adel Mohamedeen

*Vice dean for Graduate Studies and Research,
Faculty of Engineering,
Alexandria University.*

Acknowledgment

I would like to express my sincere thanks to *Prof. Dr. Mohamed Said Abougabal* and *Prof. Dr. Ahmed El Nahas* for their support, valuable comments, their guidance and useful discussions.

I would like to express my gratitude to *Prof. Dr. Mohamed Said Abougabal* and *Prof. Dr. Saleh El-Shehaby* who taught me my first course about AI from which the thesis point emerged.

I would like also to thank my family for their patience and great support.

Special thanks to *Prof. Dr. Amin Shoukry* who was the first that taught me neural networks and how to use its various models effectively.

Contents

- 1 INTRODUCTION 10**
 - 1 -1 GENERAL 10
 - 1 -2 MOTIVATION AND SCOPE OF THE WORK..... 11
 - 1 -3 ORGANIZATION OF THE THESIS 12
- 2 A TAXONOMY OF FUZZY KNOWLEDGE SYSTEMS..... 13**
 - 2 -1 INTRODUCTION 13
 - 2 -2 FUZZY SETS 14
 - 2 -3 FUZZY SET OPERATIONS 15
 - 2 -3 -1 Intersection 15
 - 2 -3 -2 Union 15
 - 2 -3 -3 Complementation 16
 - 2 -4 FUZZY KNOWLEDGE REPRESENTATION..... 16
 - 2 -5 FUZZY KNOWLEDGE ACQUISITION 16
 - 2 -5 -1 Fuzzy Knowledge Acquisition by Human Expert Experience..... 16
 - 2 -5 -2 Fuzzy Knowledge Acquisition Based on the Fuzzy Model of a Process..... 17
 - 2 -5 -3 Fuzzy Knowledge Acquisition Based on Learning..... 17
 - 2 -5 -4 Fuzzy Knowledge Acquisition Tasks..... 18
 - 2 -5 -5 Learning Techniques Used To Extract Fuzzy Knowledge 18

2 -5 -6	<i>Table Look-Ahead Techniques</i>	20
2 -5 -7	<i>Neural Networks Techniques</i>	21
2 -5 -8	<i>Neuro-Fuzzy Models</i>	23
2 -5 -9	<i>Clustering Techniques</i>	25
2 -5 -10	<i>Genetic Algorithms</i>	26
2 -6	TAXONOMY OF FUZZY INFERENCE SYSTEMS	28
2 -6 -1	<i>Taxonomy of Fuzzy Inference According To Membership Function</i>	28
2 -6 -2	<i>Taxonomy of Fuzzy Inference According To Inference Technique</i>	28
2 -6 -3	<i>Taxonomy of Fuzzy Inference According To Defuzzification Technique</i>	31
2 -6 -4	<i>Taxonomy of Fuzzy Inference According To System Input Type</i>	31
2 -6 -5	<i>Taxonomy of Fuzzy Inference According To System Output Type</i>	32
2 -7	CONCLUSION	33
3	NOVEL FUZZY KNOWLEDGE ACQUISITION TECHNIQUES	34
3 -1	INTRODUCTION	34
3 -2	THE NEED FOR A NEW FUZZY KNOWLEDGE ACQUISITION TECHNIQUE	34
3 -3	WANG TECHNIQUE	36
3 -4	MODIFIED WANG TECHNIQUE	39
3 -4 -1	<i>Eliminating Insignificant Rules</i>	40
3 -5	ADAPTATION OF MEMBERSHIP FUNCTION	41
3 -5 -1	<i>Introduction</i>	41
3 -5 -2	<i>Structure Of The Neural Network</i>	42
3 -5 -3	<i>Learning Algorithm</i>	42

3 -6	ANOTHER MODIFICATION TO WANG TECHNIQUE.....	46
3 -6 -1	<i>Introduction</i>	46
3 -6 -2	<i>Nearest Neighborhood Clustering</i>	46
3 -6 -3	<i>Extracting Fuzzy Rules.....</i>	47
3 -7	FUZZY HYBRID NEURAL NETWORKS	47
3 -7 -1	<i>Introduction</i>	47
3 -7 -2	<i>Formulation Of The Problem.....</i>	48
3 -7 -3	<i>Backpropagation Neural Network For Fuzzy Reasoning.....</i>	48
3 -7 -4	<i>The Architecture Of The Backpropagation Neural Net</i>	49
3 -7 -5	<i>Fuzzy Neural Network With Fuzzy Backpropagation.....</i>	50
3 -8	CONCLUSION.....	56
4	PERFORMANCE ANALYSIS OF THE PROPOSED FUZZY KNOWLEDGE	
	ACQUISITION TECHNIQUES.....	57
4 -1	INTRODUCTION	57
4 -2	IMPLEMENTATION OF KNOWLEDGE ACQUISITION TECHNIQUES.....	58
4 -3	DESCRIPTION OF APPLICATIONS USED IN STUDY	59
4 -3 -1	<i>Application (1): Function Approximation</i>	60
4 -3 -2	<i>Application (2): Container Crane Control</i>	60
4 -4	PERFORMANCE ANALYSIS	62
4 -4 -1	<i>Notes About Experiments.....</i>	62
4 -4 -2	<i>Accuracy Analysis.....</i>	63
4 -4 -3	<i>Sensitivity Analysis.....</i>	71

4 -4 -4 <i>Efficiency Analysis</i>	72
4 -5 CONCLUSION.....	75
5 CONCLUSION AND FUTURE EXTENSIONS.....	78
5 -1 CONCLUSION.....	78
5 -2 FUTURE EXTENSIONS.....	79
6 REFERENCES.....	80

List of Figures

FIGURE 2 • 1	CLASSIFICATION OF FUZZY KNOWLEDGE ACQUISITION.....	17
FIGURE 2 • 2	TASKS OF KNOWLEDGE ACQUISITION.....	18
FIGURE 2 • 3	CLASSIFICATION OF TRAINING TECHNIQUES FOR EXTRACTING FUZZY KNOWLEDGE.....	19
FIGURE 2 • 4	CLASSIFICATION OF TABLE LOOK-AHEAD TECHNIQUES.....	20
FIGURE 2 • 5	CLASSIFICATION OF NEURAL NETWORK STRUCTURE.....	21
FIGURE 2 • 6	CLASSIFICATION OF NEURAL NETWORK LEARNING ALGORITHMS.....	22
FIGURE 2 • 7	CLASSIFICATION OF NEURO-FUZZY MODELS.....	23
FIGURE 2 • 8	CLASSIFICATION OF CLUSTERING TECHNIQUES USED TO EXTRACT FUZZY KNOWLEDGE.....	26
FIGURE 2 • 9	CLASSIFICATION OF KNOWLEDGE ACQUISITION USING GENETIC ALGORITHMS.....	26
FIGURE 2 • 10	CLASSIFICATION OF MEMBERSHIP FUNCTION SHAPES.....	29
FIGURE 2 • 11	CLASSIFICATION OF FUZZY INFERENCE TECHNIQUES.....	30
FIGURE 2 • 12	CLASSIFICATION OF DEFUZZIFICATION TECHNIQUES.....	31
FIGURE 2 • 13	CLASSIFICATION OF SYSTEM INPUT TYPES.....	31
FIGURE 2 • 14	CLASSIFICATION OF SYSTEM OUTPUT TYPES.....	32
FIGURE 3 • 1	FUZZY SETS DEFINED ON FUZZY VARIABLE X.....	37
FIGURE 3 • 2	STRUCTURE OF THE NEURAL NETWORK USED FOR ADAPTATION.....	42
FIGURE 3 • 3	STRUCTURE OF THE HYBRID NEURAL NETWORK.....	50
FIGURE 3 • 4	FUZZY NEURON.....	51
FIGURE 3 • 5	A TRIANGULAR FUZZY NUMBER.....	52
FIGURE 3 • 6	STRUCTURE OF THE FUZZY NEURAL NETWORK.....	53
FIGURE 4 • 1	FUZZY SETS DEFINED ON FUZZY VARIABLE X.....	59
FIGURE 4 • 2	CONTAINER CRANE SYSTEM.....	61
FIGURE 4 • 3	ERROR COMPARISON FOR FUNCTION APPROXIMATION.....	64
FIGURE 4 • 4	ERROR COMPARISON FOR FUNCTION APPROXIMATION WITH 25 SAMPLES.....	66

FIGURE 4 . 5 ERROR COMPARISON FOR NON-LINEAR FUNCTION APPROXIMATION..... 68

FIGURE 4 . 6 ERROR COMPARISON FOR CONTAINER CRANE CONTROL..... 70

FIGURE 4 . 7 NUMBER OF FUNCTION EVALUATION FOR LINEAR FUNCTION APPROXIMATION..... 73

FIGURE 4 . 8 NUMBER OF FUNCTION EVALUATION FOR NON-LINEAR FUNCTION APPROXIMATION 74

FIGURE 4 . 9 NUMBER OF FUNCTION EVALUATION FOR CONTAINER CRANE CONTROL..... 74

List of Tables

TABLE 2 • 1 KNOWLEDGE ACQUISITION TECHNIQUES VS. KNOWLEDGE ACQUISITION TASKS	19
TABLE 4 • 1 HOLD OUT ERROR COMPARISON FOR FUNCTION APPROXIMATION	63
TABLE 4 • 2 CROSS VALIDATION ERROR COMPARISON FOR FUNCTION APPROXIMATION.....	64
TABLE 4 • 3 HOLD OUT ERROR COMPARISON FOR FUNCTION APPROXIMATION WITH 25 SAMPLES.....	65
TABLE 4 • 3 CROSS VALIDATION ERROR COMPARISON FOR FUNCTION APPROXIMATION WITH 25 SAMPLES	65
TABLE 4 • 5 ACCURACY ANALYSIS FOR WANG METHOD FOR FUNCTION APPROXIMATION PROBLEM ..	66
TABLE 4 • 6 HOLD OUT ERROR COMPARISON FOR FUNCTION APPROXIMATION	67
TABLE 4 • 7 CROSS VALIDATION ERROR COMPARISON FOR FUNCTION APPROXIMATION.....	67
TABLE 4 • 8 ACCURACY ANALYSIS FOR WANG METHOD FOR NON LINEAR FUNCTION APPROXIMATION PROBLEM.....	68
TABLE 4 • 9 HOLD OUT ERROR COMPARISON FOR CONTAINER CRANE CONTROL	69
TABLE 4 • 10 CROSS VALIDATION ERROR COMPARISON FOR CONTAINER CRANE CONTROL	69
TABLE 4 • 11 ACCURACY ANALYSIS FOR WANG METHOD FOR CONTAINER CRANE CONTROL	70
TABLE 4 • 12 SENSITIVITY ANALYSIS FOR LINEAR FUNCTION APPROXIMATION PROBLEM	71
TABLE 4 • 13 SENSITIVITY ANALYSIS FOR NON-LINEAR FUNCTION APPROXIMATION PROBLEM.....	71
TABLE 4 • 14 SENSITIVITY ANALYSIS FOR CONTAINER CRANE CONTROL PROBLEM	72
TABLE 4 • 15 NUMBER OF OPERATIONS.....	72
TABLE 4 • 16 EFFICIENCY OF KNOWLEDGE ACQUISITION TECHNIQUES NORMALIZED TO WANG'S EFFICIENCY	73
TABLE 4 • 17 SUMMARY OF ANALYSIS RESULTS.....	77

List of Symbols

Symbol	Meaning	Page
$\mu_A(x)$	Membership value of fuzzy set A for numerical value x	15
x_i	i^{th} fuzzy input variable	36
y_i	i^{th} fuzzy output variable	36
$x_i^{(p)}$	i^{th} fuzzy input variable for training pattern p.	36
$y_i^{(p)}$	i^{th} fuzzy output variable for training pattern p.	36
$\bar{y}$	Centroid of fuzzy variable y.	36
n	Number of input variables.	36
D(Rule i)	Degree of belief in rule	38
μ^i	Degree of belief in rule i.	15
A_i^{iq}	Fuzzy set for input variable i in rule q.	38
B_i^{iq}	Fuzzy set for output variable i in rule q.	39
m	Number of output variables.	39
M	Number of fuzzy rules in the rule base.	39
E	Error	39
N	Number of training patterns.	39
w_{ip}	weight from neuron i to neuron p	41
$Y^{(o)}$	Actual output vector.	42
Y	Desired output vector.	42
η	Learning rate.	43
e_p	Error for pattern p.	43
Z_i	Cluster center of cluster i.	46
$\tilde{I}$	Triangular fuzzy number	51

Abstract

The use of fuzzy logic to model and manage uncertainty in an expert system places high computational demands on the inference engine.

An obvious and fundamental question arising from the real implementation of an expert system is how can the knowledge be obtained. In general, this issue is termed as knowledge acquisition and is thought as a bottleneck for building a realistic expert system.

In this thesis, knowledge acquisition and fuzzy inference technique are surveyed. An automated method for extracting fuzzy rules is presented and a refinement of the membership function is performed using a feedforward neural network. Also, the fuzzy rules are refined by eliminating insignificant rules.

Two hybrid fuzzy neural systems are presented and their performance is compared to the suggested fuzzy knowledge acquisition systems.