



**UNIVERSITI PUTRA MALAYSIA**

**AN IMPROVED FUZZY PARALLEL DISTRIBUTED –LIKE  
CONTROLLER FOR MULTI-INPUT MULTI-OUTPUT TWIN ROTOR  
SYSTEM**

**THAIR SH. MAHMOUD**

**FK 2009 72**

**An Improved Fuzzy Parallel Distributed –Like Controller for Multi-Input  
Multi-Output Twin Rotor System**

**By**

**Thair Sh. Mahmoud**

**Thesis Submitted to the School of Graduate Studies, Univeristi Putra Malaysia,  
in Fulfillment of the Requirements of the Degree of Master of Science**

**May 2009**



## **DEDICATION**

**To my Parents,**

**To my Brother and Sisters,**

**To my Grandmothers**

**Thair**



Abstract of thesis presented to the Senate of University Putra Malaysia in fulfillment  
of the requirement of the degree of the Master of Science

**An Improved Fuzzy Parallel Distributed –Like Controller for Multi-Input  
Multi-Output Twin Rotor System**

By

**Thair Sh. Mahmoud**

**December 2008**

**Chairman : Assoc. Prof. Tang Sai Hong, PhD**

**Faculty : Engineering**

Twin Rotor Multi Input Multi Output (MIMO) System (TRMS) is a laboratory set-up design for which it has been used for control experiments, control theories developments, and applications of the autonomous helicopter. Fuzzy Logic Control (FLC) has been widely used with different control schemes to cope with control objectives of TRMS. In this work, Self Tuning Fuzzy PD-like Controller (STFPDC) is proposed to make the response of FLC more robust to the interactions and the non-linearity of the process in terms of less rising time, settling time and overshoot. Adaptive Neuro Fuzzy Inference System (ANFIS) based Fuzzy Subtractive Clustering Method (FSCM) was used to remodel the proposed STFPDC to achieve the control objectives on TRMS with less number of rules. MATLAB/SIMULINK was involved to achieve the simulations in this work. The results showed the



proposed controller could simplify the STFPDC to reduce the number of rules from 392 to 73, which is even less than the original FLC that has 196 rules.

The conclusion of this work is improving FLC response by using STFPDC and reducing the number of rules used to achieve this improvement by using ANFIS based on FSCM modeling. For future works, it is recommended to develop an optimization algorithm which achieves best selection for the range of influence which gives best response with less number of rules.

Abstrakt tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

**Kawalan Bagai Agihan Selari Kabur Yang Diperbaharui Bagi Sistem Putaran  
Kembar Pelbagai Input Pelbagai Output**

Oleh

**Thair Sh. Mahmoud**

**Disember 2008**

**Pengerusi : Prof. Madya Tang Sai Hong, PhD**

**Fakulti : Kejuruteraan**

Sistem Rotor Kembar Pelbagai Input Pelbagai Output (MIMO) (TRMS) adalah satu reka cipta makmal yang sebelum ini digunakan untuk uji kaji kawalan, pembangunan teori kawalan dan aplikasi helikopter autonom. Kawalan logik kabur (FLC) telah banyak digunakan dengan skim kawalan yang berbeza bagi menampung tujuan kawalan TRMS. Dalam tugas ini, pengawal kabur putaran sendirian bagi PD (STFPDC) dicadangkan untuk menjadikan gerak balas lebih tegap daripada FLC biasa bagi interaksi dan proses yang taksekata dari segi pengurangan masa bangkit, masa tinggal dan keterlanjuran. Cara gugusan penolakan kabur yang berdasarkan sistem kesimpulan kabur penyesuaian saraf (ANFIS) telah digunakan untuk mengubah bentuk cadangan STFPDC untuk mencapai tujuan kawalan TRMS dengan bilangan peraturan yang kurang. MATLAB/SIMULINK telah dilibatkan untuk mencapai simulasi dalam tugas ini. Keputusan ini menunjukkan sistem kawalan yang dicadangkan boleh memudahkan STFPDC dengan mengurangkan bilangan

peraturan daripada 392 peraturan kepada 73 peraturan, malah kurang daripada FLC tulen yang mempunyai 196 peraturan.

Kesimpulan tugas ini ialah memperbaiki gerak balas FLC dengan menggunakan STFPDC dan mengurangkan bilangan peraturan yang digunakan untuk mencapai perbaikian dengan penggunaan pemodelan FSCM berdasarkan ANFIS. Bagi tugas yang akan datang, ia dipertimbangkan untuk memajukan satu algoritme optimasi di mana ia mencapai pilihan terbaik bagi banjaran pengaruh yang memberi gerak balas terbaik dengan bilangan peraturan yang kurang.

## ACKNOWLEDGEMENTS

I would like to thank many people who assisted me to finish the research. My appreciation and thank to my supervisor, Assoc. Prof. Dr. Tang Sai Hong, for his help and support along with duration of doing this research. I would like to provide my warm appreciation to Assoc. Prof. Dr. Mohammed Hamiruce Marhaban who has provided me with guidance and knowledge support along with the duration of doing this research.

I take this opportunity to formally thank my fellow house mates, for their help and support throughout the whole project.

I would also especially like to thank my family who has always believed in me.

Thair Sh. Mahmoud

May 2009





I certify that an Examination Committee has met on 11 May 2009 to conduct the final examination of Thair Sh. Mahmoud on his thesis entitled "An Improved Fuzzy Parallel Distributed-Like Controller for Multi-Input Multi-Output Twin Rotor System" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 15 March 1998]. The Committee recommends that the student be awarded the Master of Science.

Members of the Thesis Examination Committee were as follows:

**Samsul Bahari Mohd Noor , PhD**

Lecturer  
Faculty of Engineering  
Universiti Putra Malaysia  
(Chairman)

**Mohd Sapuan Salit, PhD**

Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Internal Examiner)

**Napsiah Ismail, PhD**

Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Internal Examiner)

**Mohd Rizal Arshad, PhD**

Professor  
Faculty of Computer Science  
Universiti Sains Malaysia  
(External Examiner)

---

**BUJANG KIM HUAT, PHD**

Professor/Deputy Dean  
School of Graduate Studies  
Universiti Putra Malaysia

Date: 28 June 2009



This thesis submitted to the Senate of University Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the Supervisory are as follow:

**Tang Sai Hong, PhD**

Associate Professor  
Faculty of Engineering  
Department of Mechanical and Manufacturing Engineering  
University Putra Malaysia  
(Chairman)

**Mohammed Hamiruce Marhaban, PhD**

Associate Professor  
Faculty of Engineering  
Department of Electrical and Electronics Engineering  
University Putra Malaysia  
(Member)

---

**HASANAH MOHD. GHAZALI, PhD**

Professor/Deputy Dean  
School of Graduate Studies  
Universiti Putra Malaysia

Date: 17 July 2009



## **DECLARATION**

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

---

**Thair Sh. Mahmoud**

Date: 11 May 2009

## TABLE OF CONTENTS

	<b>Page</b>
<b>DEDICATION</b>	ii
<b>ABSTRACT</b>	iii
<b>ABSTRAK</b>	v
<b>ACKNOWLEDGEMENTS</b>	vii
<b>APPROVAL</b>	viii
<b>DECLARATION</b>	x
<b>LIST OF TABLES</b>	xiv
<b>LIST OF FIGURES</b>	xv
<b>LIST OF ABBREVIATIONS AND NOTATIONS</b>	xix
 <b>CHAPTER</b>	
<b>1 INTRODUCTION</b>	
1.1 Background	1
1.2 Problem Statement	2
1.3 Aims and Objectives of the Research	3
1.4 Scope of The Work	4
1.5 Thesis Outlines	5
<b>2 LITERATURE REVIEW</b>	
2.1 Introduction	7
2.2 Twin Rotor MIMO System	8
2.3 Twin Rotor MIMO System Modeling and Control Challenges	13
2.3.1 Twin Rotor MIMO System Modeling Challenges	13
2.3.2 Twin Rotor MIMO System Control Challenges	20
2.4 Self-Tuning Fuzzy PD-like Controller	26
2.5 Fuzzy Subtractive Clustering Method	27
2.6 Adaptive Neural Fuzzy Inference Systems (ANFIS)	29
2.7 Summary	31
<b>3 METHODOLOGY</b>	
3.1 Introduction	33
3.2 Fuzzy Controller Design	35
3.2.1 Fuzzy Controller Design of one DOF Motion Control of Twin Rotor MIMO System	36
3.2.2 Fuzzy Controller Design of two DOF Motion Controls of Twin Rotor MIMO System	39
3.3 Self Tuning Fuzzy PD-like Controller Design	42
3.3.1 Self Tuning Fuzzy PD-like Controller Design of one DOF Motion Control of Twin Rotor MIMO System	42
3.3.2 Self Tuning Fuzzy PD-like Controller Design of two DOF Motion Controls of Twin Rotor MIMO System	43
3.4 Self Tuning Fuzzy PD-like Controller Training	45
3.5 Clusters Estimation	47
3.6 Rules Training	48
3.7 Memory and Time Calculations	49
3.8 Summary	52



<b>4</b>	<b>RESULTS AND DISCUSSIONS</b>	
4.1	Introduction	53
4.2	Horizontal Part Control Of one DOF Motion Of TRMS	54
4.2.1	Self Tuning Fuzzy PD-Like Controller With Step Input Response in Horizontal Part of one DOF Motion Control of TRMS	54
4.2.2	Data Generation of The Horizontal Part of one DOF Motion Control of TRMS	56
4.2.3	Network Structure of the STFPDC of Horizontal Part of one DOF Motion Control of TRMS	57
4.2.4	Membership Functions Training of the Horizontal Part of one DOF Motion Control of TRMS	59
4.2.5	Final Membership Functions Shapes and Positions of the Horizontal Part of one DOF Motion Control of TRMS	60
4.2.6	ANFIS-STFPDC Response with Step and Sinusoidal Input Signals of Horizontal Part of one DOF Motion Control TRMS	61
4.2.7	ANFIS and FLC Response Comparison of Horizontal Part of one DOF Motion Control of TRMS	63
4.2.8	ANFIS and Self Tuning Fuzzy PD-Like Controller Responses Comparison of Horizontal Part of one DOF Motion Control of TRMS	64
4.3	Vertical Part Control of one DOF Motion Control of TRMS	66
4.3.1	Self Tuning Fuzzy PD-Like Controller With Step Input Response in Vertical Part of one DOF Motion Control of TRMS	66
4.3.2	Data Generation of the Vertical Part of one DOF Motion Control of TRMS	68
4.3.3	Network Structure of the Vertical Part of one DOF Motion Control of TRMS	69
4.3.4	Membership Functions Training of Vertical Part of one DOF Motion Control of TRMS	70
4.3.5	Final Membership Functions Shapes and Positions of Vertical Part of one DOF Motion Control of TRMS	71
4.3.6	ANFIS-STFPDC Response with Step and Sinusoidal Input Signals of Vertical Part of one DOF Motion Controls TRMS	73
4.3.7	ANFIS and FLC Responses Comparison of Vertical Part of one DOF Motion Control of TRMS	75
4.3.8	ANFIS and Self Tuning Fuzzy PD-like Controller Responses Comparison of Vertical Part of one DOF Motion Control of TRMS	76
4.4	Cross Couple Control of TRMS	79
4.4.1	Self Tuning Fuzzy PD-like and Fuzzy Logic Controllers Responses Comparisons in two DOF Motion Control of TRMS	79

4.4.2	Data Generation for The Four Controllers of two DOF Motion Controls of TRMS	80
4.4.3	Network Structures of The two DOF Motion Controls of TRMS	84
4.4.4	Membership Functions Extraction of The two DOF Motion Controls of RMS	87
4.4.5	Final Membership Functions Shapes and Positions of the two DOF Motion Controls of TRMS	90
4.4.6	ANFIS-Self Tuning Fuzzy PD-like Controller and Fuzzy Logic Controller Responses Comparison	95
4.4.7	ANFIS-Self Tuning Fuzzy PD-like Controller and Self Tuning Fuzzy PD-Like Controller Responses Comparison	97
4.5	Summary	99
<b>5</b>	<b>CONCLUSION</b>	
5.1	Conclusion	101
5.2	Future Work	102
	<b>REFERENCES</b>	103
	<b>APPENDICES</b>	112
	<b>BIODATA OF STUDENT</b>	119

## LIST OF TABLES

<b>Table</b>		<b>Page</b>
2.1	Two Passes in The Hybrid Learning Procedure for ANFIS	31
3.1	Rules Table for the Proposed Fuzzy Systems	38
3.2	One DOF FLC Design Parameters of TRMS	39
3.3	Two DOF FLC Design Parameters of TRMS	40
3.4	One DOF Motion STFPDCs Design Parameters of TRMS	42
3.5	Two DOF Motion STFPDCs Design Parameters of TRMS	44
4.1	ANFIS-STFPDC and FLC Results Comparisons with Other Works For Step Input Response on Horizontal Part of one DOF Motion Control of TRMS	66
4.2	ANFIS-STFPDC and FLC Results Comparisons with Other Works For Step Input Response on Vertical Part of one DOF Motion Control of TRMS	78
4.3	ANFIS-STFPDC Improvements in two DOF Motion Controls of TRMS	99

## LIST OF FIGURES

Figure		Page
2.1	Schematic Diagram of TRMS	8
2.2	Main Rotor Blades System	9
2.3	Position Sensor	11
2.4	TRMS Showing Location of Locking Screws	12
2.5	Simulink® Model for Horizontal Part of TRMS	14
2.6	Simulink® Model for Vertical Part of TRMS	15
2.7	Simulink® Detailed 2-DOF Model of TRMS	16
2.8	Self Tuning Fuzzy PD-like Controller Scheme	26
2.9	Adaptive Neuro Fuzzy Inference System Structure	29
3.1	Controller Evolution throughout This Work	33
3.2	Methodology Flow Chart	34
3.3	Fuzzy Logic Controller for one DOF; (A) Represents Horizontal Part and (B) is the Vertical Part of one DOF Motion Controls of TRMS	36
3.4	Configuration of Two Inputs PD-like FLC	37
3.5	Cross Coupled (two DOF) TRMS Control System with FLCs	40
3.6	Membership Functions Design for FLC of Horizontal Part of one DOF Motion Control of TRMS	41
3.7	Membership Functions Design for FLC of Vertical Part of one DOF Motion Control of TRMS	41
3.8	Membership Functions Design for STF of Horizontal Part of two DOF Motion Controls of TRMS	43
3.9	Cross Coupled (two DOF) TRMS Control System Simulink Model with STFPDCs	45



3.10	Self Tuning Fuzzy PD-like Controller Training Structure	46
3.11	Mechanism of Using Data for Identification and Learning of New FIS Using ANFIS Structure	46
3.12	Error Training with Specified Number of	48
3.13	ANFIS Parameters Training Scheme	49
3.14	MATLAB/Simulink Profiler Window	50
3.15	Windows Task Manager Window	51
4.1	STFPDC Step Input Response of Horizontal Part in one DOF Motion Control of TRMS	55
4.2	STFPDC and FLC with Step Input Responses of Horizontal Part of one DOF Motion Control of TRMS	56
4.3	Training Data of Horizontal Part STFPDC in one DOF Motion Control of TRMS	57
4.4	Extracted Network Structure of the STFPDC of Horizontal Part In one DOF Motion Control of TRMS	58
4.5	MATLAB/ANFIS Window Showing Training Error Decreased during Learning for Horizontal Part in one DOF Motion Control of TRMS	60
4.6	Extracted Membership Functions for Horizontal Part Controller of one DOF Motion Control of TRMS	61
4.7	Final Membership Functions Shapes in Horizontal Part of one DOF Motion Controls of TRMS after Training	61
4.8	Step Input Response of the Proposed ANFIS-STFPDC in Horizontal Part of one DOF Motion Control of TRMS	62
4.9	Sinusoidal Input Response of the Proposed ANFIS-STFPDC for Horizontal Part of one DOF Motion Control of TRMS	63
4.10	Step Input Responses Comparison between ANFIS-STFPDC and FLC in Horizontal Part of one DOF Motion Control of TRMS	64
4.11	Step Input Responses Comparison between ANFIS-STFPDC and STFPDC in Horizontal Part of one DOF Motion Control of TRMS	65
4.12	STFPDC Step Input Response of Vertical Part of one DOF Motion Control of TRMS	67

4.13	STFPDC and FLC with Step Input Responses of Vertical Part of one DOF Motion Control of TRMS	68
4.14	Training Data of Vertical Part STFPDC in one DOF Motion Control of TRMS	69
4.15	Extracted Network Structure of The STFPDC of The Vertical Part of TRMS	70
4.16	MATLAB/ANFIS Window Showing Training Error Decreased during Learning for Vertical Control Part of TRMS	71
4.17	Extracted Membership Functions for Vertical Part of one DOF Motion Control of TRMS	72
4.18	Final Membership Functions Shapes for Vertical Part of one DOF Motion Control of TRMS	72
4.19	Step Input Response of the Proposed ANFIS-STFPDC for Vertical Part of one DOF Motion Control of TRMS	73
4.20	Square Input Response of the Proposed ANFIS-STFPDC for Vertical Part of one DOF Motion Control of TRMS	75
4.21	Step Input Responses Comparison between ANFIS-STFPDC and FLC in Vertical Part of one DOF Motion Control of TRMS	76
4.22	Step Input Responses Comparison between ANFIS-STFPDC and STFPC in Vertical Part of one DOF Motion Control of TRMS	77
4.23	Comparison between STFPDC and FLC in two DOF motion controls of TRMS	80
4.24	Training Data of Horizontal Part STFPDC in two DOF Motion Controls of TRMS	82
4.25	Training Data of Horizontal to Vertical Interaction Part STFPDC in two DOF Motion Controls of TRMS	83
4.26	Training Data of Vertical to Horizontal Interaction Part STFPDC in two DOF Motion Controls of TRMS	83
4.27	Training Data of Vertical Part STFPDC in two DOF Motion Controls of TRMS	84
4.28	Extracted Network Structure of the STFPDC of Horizontal Part in two DOF Motion Controls of TRMS	85
4.29	Extracted Network Structure of the STFPDC of the Vertical to Horizontal Interaction Part in two DOF Motion Controls of TRMS	86



4.30	Extracted Network Structure of the STFPDC of the Vertical Part in two DOF Motion Controls of TRMS	86
4.31	Training Error for Horizontal Part in two DOF Motion Controls of TRMS	88
4.32	Training Error for Horizontal to Vertical Interaction Part of two DOF Motion Controls of TRMS	88
4.33	Training Error for Horizontal to Vertical Interaction Part of two DOF Motion Controls of TRMS	89
4.34	Training Error for Vertical Part in two DOF Motion Controls of TRMS	89
4.35	Extracted Membership Functions for Horizontal Part Controller of two DOF Motion Controls of TRMS	91
4.36	Final Membership Functions Shapes for Horizontal Part of two DOF of TRMS after Training	91
4.37	Extracted Membership Functions for Horizontal to Vertical Interaction Part Controller of two DOF Motion Controls of TRMS	92
4.38	Final Membership Functions Shapes for Horizontal to Vertical Interaction Part Controller of two DOF Motion Controls of TRMS	92
4.39	Extracted Membership Functions for Vertical to Horizontal Interaction Part Controller of two DOF Motion Controls of TRMS	93
4.40	Final Membership Functions Shapes for Vertical to Horizontal Interaction Part Controller of two DOF Motion Controls of TRMS	94
4.41	Extracted Membership Functions for Vertical Part Controller in two DOF Motion Controls of TRMS	94
4.42	Final Membership Functions Shapes for Vertical Part Controller of two DOF Motion Controls of TRMS	95
4.43	Comparison between ANFIS-STFPDC and FLC of two DOF Motion Controls of TRMS	96
4.44	Comparison between ANFIS-STFPDC and STFPDC in two DOF Motion Controls of TRMS	97
4.45	The Evolution of the Response with Computation Resources Considerations	98

## LIST OF ABBREVIATIONS AND NOTATIONS

<b>AI</b>	Artificial Intelligence
<b>ANFIS</b>	Adaptive Neuro Fuzzy Inference System
<b>CGA</b>	Conjugate Gradient Algorithm
<b>CPU</b>	Central Processing Unit
<b>D/A</b>	Digital to Analog converter
<b>DC</b>	Direct Current
<b>DOF</b>	Degree Of Freedom
<b>FIS</b>	Fuzzy Inference System
<b>FSCM</b>	Fuzzy Subtractive Method
<b>GUI</b>	Graphic User Interface
<b>HLA</b>	Hybrid Learning Algorithm
<b>ITSE</b>	Integral of Time Multiplied by Square Error Criterion
<b>LQ</b>	Linear Quadratic
<b>MIMO</b>	Multi Input Multi Output
<b>MLP</b>	Multi Layer Preceptron
<b>MRAN</b>	Minimal Resource Allocating network
<b>NARX</b>	Non-linear Auto Regressive process with eXternal input
<b>NN</b>	Neural Networks
<b>PDC</b>	Parallel Distributed Compensator
<b>PID</b>	Proportional Integral Derivative
<b>PSO</b>	Particle Swarm Optimization
<b>RBF</b>	Radial Basis Function
<b>RGGA</b>	Real valued Genetic Algorithms
<b>RLS</b>	Recursive Least Square
<b>STFPDC</b>	Self Tuning Fuzzy PD-like Controller



<b>SISO</b>	Single Input Single Output
<b>SNN</b>	Single Neural Net
<b>TRMS</b>	Twin Rotor MIMO System
<b>TSK</b>	Takagi-Sugeno-Kang
<b>UAV</b>	Unmanned air Vehicle

# CHAPTER 1

## INTRODUCTION

### 1.1 Background

In recent years, Unmanned Aerial Vehicles (UAVs) have attracted significant research interests. UAVs can do piloted aerial vehicles jobs in risky places without risking pilot's life. UAVs are very useful in doing missions in hostile environments. Unmanned helicopters have practical interesting dynamic features among autonomous flying systems. The main difficulties in designing controllers for them come from nonlinearities and couplings.

Twin Rotor MIMO System (TRMS) is a laboratory set-up design for which it has been used for control experiments, control theories developments, and applications of the autonomous helicopter. Basically, it resembles in certain aspects the behavior of helicopter. It introduces some of the platforms and control architectures, and exemplifies a high order non-linear system with significant cross-couplings from control engineering point of view. A detailed approach to the control problems connected with the TRMS involves some theoretical knowledge of laws and physics (Feedback Corp. 1998).

Modeling and controlling of TRMS are considered challenging for control community. It has attracted many researchers in the last decade. The researchers have started working of



solving TRMS control problems with conventional PID controller. It seems to be inadequate for this complex problem, and resulting to a poor performance with the non-linearity and coupling effects. PID controller performance can be improved by adjusting gains, but this still has its limitation (Juang and Liu, 2006a). Artificial intelligence has also been used to improve control performance and reduce interactions effects.

Artificial Intelligence (AI) is necessary to achieve successful embedded control systems with good control performance. So, computation resources and complexity of the used AI algorithm need to be considered for less computation resources and more flexibility in developing the embedded software's that achieve the control objectives on the systems.

## **1.2 Problem Statement**

TRMS control has been studied in the last few years as it represents a control and modeling challenge for researchers. Fuzzy Logic Control (FLC) has been widely used with different control schemes to cope with control objectives of TRMS. It has been shown that FLC was superior to classical controllers in terms of tracking and transient response of TRMS (Islam *et al.*, 2003; Juang and Liu, 2006a). FLC has been utilized in many different hybrid schemes, and implemented with the use of classical and/or intelligent control like Genetic Algorithms (GA). As mentioned by many researchers (Jang *et al.*, 2005; Adebrez *et al.*, 2006; Rahideh *et al.*, 2006; Jang *et al.*, 2006a, 2006b;



Jang *et al.*, 2008), fuzzy logic has been proposed in different schemes with the use of Genetic Algorithms (GA) and conventional PID controller.

From the literature, it looks that the limitation of FLC is related to the difficulty in predicting changes in the operating conditions of a system and then adjusting for them. Hence, it is desirable to develop a self-tuning fuzzy controller that can improve FLC performance based on its experience, and to adapt its response in relation to variations in TRMS dynamics (Zhang and Liu, 2006).

In this work Self Tuning Fuzzy PD-like Controller (STFPDC) is proposed to make the response more robust to the interactions and non-linearity of the process. For this work, it is obvious that STFPDC scheme is using eight fuzzy reasoning blocks; each with forty-nine rules at least for this system. The eight fuzzy reasoning blocks are needed to achieve control objectives for horizontal, vertical, and the two de-coupling parts; each with two fuzzy reasoning blocks. It is considered complex control scheme with high number of the used fuzzy rules.

### **1.3 Aims and Objectives of the Research**

The aims of this study is to improve FLC trajectory tracking performance and reduce cross coupling of TRMS by adding self tuning fuzzy inference system to the original FLC. Then, ensure achieving same control objectives with simpler control strategy in terms of less number of rules.





To achieve these aims, three specific objectives need to be achieved:

- i) Proposing Self Tuning Fuzzy PD-like Controllers to improve FLC response in terms of solving control problems and interactions between each degree of freedom.
- ii) Developing an Adaptive Neural Fuzzy Inference System (ANFIS) based on Fuzzy Subtractive Clustering Method (FSCM) from the original proposed Self Tuning Fuzzy PD-like Controllers.
- iii) Controlling TRMS with new Adaptive Neuro Fuzzy Inference Systems based Self Tuning Fuzzy PD-Like Controllers.

#### **1.4 Scope of the Work**

In this work, ANFIS-STFPDC based Fuzzy Subtractive Clustering Method (FSCM) is proposed to control TRMS. This work will neither cover optimization of achieving best parameters selections of FLC nor any method achieve best selection of range of influence in FSCM. This project will try to solve trajectory and interaction problems between yaw and pitch angles of TRMS with better response than that of FLC using STFPDC. This work will achieve same performance of STFPDC with less number of rules. In this work, all the simulations and designs are made under MATLAB®/SIMULINK®.

