INTELLIGENT ROBUST CONTROL OF PRECISION POSITIONING SYSTEMS USING ADAPTIVE NEURO FUZZY INFERENCE SYSTEM

BY

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ABSTRACT

Recently, there has been an increasing interest in the application of robust control theory for Precision Positioning Systems (PPS). This is mainly driven by the need to provide guaranteed stability in spite of uncertainties and disturbances associated with these systems. However, robust control techniques require a dynamic model of the plant under study and bounds on modelling uncertainty to develop control laws with guaranteed stability. Although identification techniques for modelling dynamic systems and estimating model parameters are well established, very few procedures exist for estimating uncertainty bounds. A conservative bound is usually chosen to ensure robust stability for a reasonable range of variations about the nominal model. Nevertheless, high performance requirement of PPS will be severely affected. In this research an intelligent uncertainty function is developed to improve the performance of H_∞ robustly controlled high precision positioning system in terms of reduced conservatism. The proposed approach can be systematically applied. First, the nominal model of the positioning system is identified; output performance and control signal requirements are then determined by proper selection of performance and control weighting functions. Adaptive Neuro Fuzzy Inference System (ANFIS) is used to produce the uncertainty bounds of model uncertainty that results from unmodeled dynamics and parameter variations. The synthesis of the H_∞ controller will incorporate these weighting functions. Then to further improve the controlled system performance, an unconstrained optimization procedure is developed to obtain the best possible performance weighting function. Moreover, an intelligent disturbance weighting function is developed to eliminate the effect of crosstalk between the axes. v-gap metric is utilized to validate the identified uncertainty set for robust controller design. μ-analysis is used to evaluate the robustness of the system. The computational time and number of iterations of the proposed intelligent estimation method are decreased to < 0.1 of that required by a neural network method with less or equal v-gap metric value. Simulation and experimental results using different servo motion plants reveal the advantages of combining intelligent uncertainty identification and robust control. Improved performance has been achieved for rotational motion, single axis and two-axis servo systems. Settling time <0.8 seconds, rise time < 0.5 and steady state error within sensor resolution are achieved for the rotational motion system. In the case of the X-Y positioning systems, tracking errors are reduced to less than 100% of that obtained using a well tuned conventional PID controller and less than 10% of that obtained using a nominal H_∞ robust controller. v-gap metric value of <1.0 and larger stability region can be readily obtained for both cases. Robust stability and performance are also guaranteed. The generality of the problem formulation enables the application for more complicated systems.

خلاصة البحث

لقد أزداد مؤخرا الأهتمام بتطبيق نظرية السيطرة المتينة على أنظمة الحركة ذات الدقة العالية. ويعود السبب في ذلك للحاجة الماسة لتوفير سيطرة مؤكدة على هذه المنظومات حتى في حال وجود عدم وثوقية أو اضطرابات مرافقة. و حيث ان تقنيات السيطرة المتينة تتطلب توفير نموذج ديناميكي محدد للنظام قيد الدراسة بالأضافة الى تعريف حدود عدم الوثوقية في النموذج. و على الرغم من توفر تقنيات متطورة لتمثيل الأنظمة الديناميكية و تعريفها و تخمين عواملها لا نجد الا طرق قليلة لتعريف حدود عدم الوثوقية. و لقد جرت العادة على اختار حدود عدم وثوقية محافظة للحصول على السيطرة المتينة مما يؤثر سلبا على نوعية المتطلبات العالية لأداء منظومة الحركة الدقيقة . لذلك تم في هذا البحث تطوير دالة كشف عدم وثوقية ذكية لتحسين السيطرة و الأداء المتينين لمنظومة سيطرة عالية الدقة باستخدام H_∞ مع تقليل المحافظة الزائدة. بالأمكان تطبيق الطريقة المقترحة بشكل منظم حيث يتم في البداية تعريف منظومة الحركة المعنية, ولتوفير متطلبات اشارة السيطرة و الاداء الخارجي يتم اختيار دوال اهمية مناسبة لهذا الغرض, و من ثم يتم تعليم منظومة ذاتية التكيف ذات نظام عشوائي- عصبي ANFIS لموائمة تأثير حدود عدم الوثوقية الناتجة عن العوامل الديناميكية الغير معرفة او المتغيرة بشكل دقيق. ويتم بعد ذلك تركيب مسيطر متين H_∞ بالأستفادة من دوال الأهمية المستحصلة سابقا. و لزيادة تحسين أداء منظومة السيطرة تستخدم خطوات تحسين أمثل غير مقيدة للحصول على افضل دالة اهمية للآداء. بالأضافة الى تعريف دالة أهمية ذكية أخرى للتخلص من تأثيرات الأضطراب الناتجة من التعشيق بين المحاور الحركيية المتعددة. و لقد استخدمت الفجوة المترية-ν للتصديق على دقة مجموعة عدم الوثوقية المعرفة. كما تم استخدام طريقة μ لتحليل مدى متانة المنظومة الناتجة. كشفت نتائج تجارب المحاكاة و التطبيق العملي للمسيطر الذكي المتين على أكثر من جهاز حركة دقيقة عن فوائد الجمع بين التعريف الذكي لحدود عدم الوثوقية و السيطرة المتينة. حيث تم الحصول على تحسن باداء منظومتي حركة دقيقة احادية و ثنائية المحاور. كذلك تم تحقيق قيم صغيرة للفجوة المترية- ν مع مساحة سيطرة كبيرة, حيث تم الحصول على سيطرة و اداء متينين. بالاضافة الى تحسن عالي بأداء المسار و الخطط لمنظومة ثنائية المحاور مما يدل على مدى فاعلية الطريقة الستخدمة. ان الطريقة المقترحة ذات خاصية عمومية شاملة و عملية مما يتيح امكانية تطبيقها لمنظومات أكثر تعقيدا.

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DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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TABLE OF CONTENTS

Abstract ii
Abstract in Arabic iii
Approval Page iv
Declaration Page v
Copyright Page vi
Acknowledgements vii
List of Tables xii
List of Figures xiv
List of Abbreviation xxiii
List of Symbols xxvii

CHAPTER ONE: INTRODUCTION 1
1.1 Overview 1
1.2 Problem Statement and its Significance 3
1.3 Research Philosophy 4
1.4 Research Objectives 5
1.5 Research Methodology 5
1.6 Scope of the Research 7
1.7 Thesis Organisation 8

CHAPTER TWO: LITERATURE REVIEW 11
2.1 Introduction 11
2.2 High Precision Positioning Systems 13
2.2.1 Types of Motion Converters 13
2.2.2 Types of Servomotors 15
2.2.3 High Precision Motion Servo Drives 16
2.3 Adaptive Robust Controller 17
2.3.1 Friction Compensation 17
2.3.2 Disturbance Observer Based Robust Control System 18
2.3.3 Adaptive Robust Based Controller 21
2.4 Robust Adaptive Sliding Mode Controller 23
2.5 Nominal Characteristic Trajectory Following Control 24
2.6 Robust Cross Coupled Based Controller 25
2.7 Iterative Learning Based Control 27
2.8 Intelligent Controller 30
2.8.1 Neural Network Based Controller 31
2.8.2 Fuzzy Controller 32
2.8.3 Fuzzy Neural Controller 34
2.9 Robust Controller 35
2.9.1 Quantified Feedback Theory (QFT) Based Robust Control 36
2.9.2 H_∞ Optimization 36
2.9.3 H_∞ Loop Shaping 39

2.9.4 Linear Matrix Inequality (LMI) Approach 40
2.9.5 Robust Controller Using Intelligent Techniques 41
2.10 Adaptive Network Based Fuzzy Inference System for Uncertainty Estimation 43
2.10.1 ANFIS Structure... 44
2.10.2 ANFIS for Estimation of Uncertainties..................................... 48
2.11 Summary 50

CHAPTER THREE: MODELLING AND IDENTIFICATION OF SERVO-POSITIONING SYSTEM 51
3.1 Introduction 51
3.2 Rotational Servo Motion System 52
3.3 Single Axis Positioning Table 52
3.4 X-Y Positioning System 56
3.5 The Nonlinearities of the Servo Positioning Systems........................... 58
3.5.1 Nonlinear Friction 58
3.5.2 Amplifier Saturation... 67
3.5.3 Eccentricity 68
3.5.4 Backlash 69
3.6 Parametric Identification of Servo System's Nominal Model 70
3.6.1 The Linear Continuous Time Process Model Determination 71
3.6.2 Experimental Identification of a Rotational DC Servo System ... 72
3.6.3 Experimental Identification of Single Axis Servo System 75
3.6.4 Experimental Identification of X-Y Table Driven Servo System 79
3.7 Summary 82

CHAPTER FOUR: ROBUST IDENTIFICATION AND UNCERTAINTY REPRESENTATION 84
4.1 Introduction 84
4.2 Modelling of Uncertainties 85
4.2.1 Models for High Performance Control-Design Problem 87
4.3 Uncertainty Representation for Servo Positioning System.................... 88
4.3.1 Parametric Representation for the servo Motor System 89
4.3.2 Unstructured Uncertainty Representation for Servo Positioning System 96
4.4 Robust Identification.. 99
4.4.1 Model Error Modelling (MEM) 102
4.4.2 Estimating Model Uncertainty for Servo System 105
4.5 Summary 113

CHAPTER FIVE: INTELLIGENT IDENTIFICATION OF UNCERTAINTY BOUND USING ANFIS 114
5.1 Introduction 114
5.2 Implementation of ANFIS for Identification of Uncertainty Bounds.... 115
5.2.1 Intelligent Uncertainty Weighting Function using ANFIS in

Feedback 116
5.3. Model Validation and Robust Stability Measure 118
5.3.1 ν-Gap Metric 119
5.4. Design of Robust H_∞ controller 121
5.4.1 Mixed Sensitivity Performance Weights 121
5.4.2 Description of the H_∞ Control Problem 124
5.5 Experimental Work 126
5.5.1 Experimental Uncertainty Identification Using ANFIS1 126
5.5.2 Experimental Uncertainty Identification Using ANFIS2 135
5.5.3 Intelligent Robust Estimation of Uncertainty Bounds of an Active Magnetic Bearings (AMB) 147
5.6 Summary 151

CHAPTER SIX: INTELLIGENT ROBUST CONTROLLER DESIGN OF A SINGLE AXIS POSITIONING SYSTEM 152
6.1 Introduction 152
6.1.1 Basic Notations and Definitions..153
6.2 Optimized Performance Weighting 153
6.3 Robust Controller Design and Analysis..156
6.4 Robust Controller Design Using Structured Parametric Uncertainties..157
6.5 μ Stability and Performance Analysis..159
6.6 Experimental Work and Results 165
6.6.1 System Description 165
6.6.2 Robust Controller Based on Parametric Uncertainties 165
6.6.3 Intelligent Robust Controller Implementation 170
6.6.4 Improving Tracking Performance 176
6.7 Summary 185

CHAPTER SEVEN: INTELLIGENT ROBUST CONTROLLER DESIGN OF A TWO- AXIS POSITIONING SYSTEM 187
7.1 Introduction..187
7.2 X-Y Positioning System; Problem Statement and Formulation 188
7.3 H_∞ Robust Control Synthesis 193
7.4 Simulation Results 196
7.4.1 The Intelligent Uncertainty Weighting Function 197
7.4.2 The Intelligent Disturbance Weighting Function.........................197
7.4.3 H_∞ Robust Controller Design and Analysis 200
7.4.4 Comparison with PID Controller 203
7.4.5 Tracking Performance Measures..206
7.5 Experimental Work and Results 211
7.6 Summary 223

CHAPTER EIGHT: CONCLUSION AND RECOMENDATION...................225
8.1 Summary of Results 225
8.2 Contribution of the Thesis 227
8.3 Recommendations for Future Work...228

REFERENCES 230

APPENDIX I Some Applications of ANFIS in Modelling and Identification of System's Uncertainties...247
APPENDIX II Summary of Literature Review 249
APPENDIX III Quanser Servo Motion System..252
APPENDIX IV Linear Regression Identification...254
APPENDIX V Linear Fractional Transformation 256
APPENDIX VI Robust Identification Algorithms 257
APPENDIX VII Robust Stability Check by the *v*-Gap Metric Using the Frequency-by Frequency Test 260
APPENDIX VIII Summary of Robust Control Theory..261
APPENDIX IX Intelligent Estimation of Uncertainty Bound Using Confidence Interval Network CIN...264
APPENDIX X Solving the Problem of Having a Pole in the Origin 267
APPENDIX XI Program Codes...268
APPENDIX XII Analytical Model of Active Magnetic Bearing 286
APPENDIX XIII MATLAB Optimization Function *fmincon*................................287
APPENDIX XIV Experimental Data of Tables in Chapter Six 288
APPENDIX XV Experimental Data of Tables in Chapter Seven 290

LIST OF TABLES

Table No.		Page No.
2.1	Hybrid learning procedure for ANFIS	49
3.1	Identification results for different input signals	74
3.2	Comparison between three different identified nominal models of the positioning system	80
3.3	The PEM Identification Results of the X Axis	82
3.4	The PEM identification results of the Y Axis	82
4.1	SRV02 system parameter	91
4.2	Sources of perturbations in a standard identification problem	100
4.3	Different estimated PEM models within MEM framework	107
5.1	Validation of uncertainty weighting function using v- gap	131
5.2	A comparison between three methods of evaluating the uncertainty weighting function	132
5.3	Robustness test: tracking performance using different Uncertainty weighting functions	134
5.4	Weighting functions of different order models, with corresponding controllers and γ values	140
5.5	Intelligent identified uncertainty validation using v-gap, for square input data signal	141
5.6	Intelligent identified uncertainty validation using v-gap, for sinusoidal input data signal	147
5.7	Intelligent identified uncertainty validation, using v-gap for sawtooth input data signal	147
5.8	Comparison between two intelligently identified uncertainty weighting functions	150
6.1	Validation and robust stability test of W_a for robust controlled System	173

6.2	Performance measures of the robustly controlled system using parametric and unstructured additive uncertainty representations	176
6.3	Performance measures of I- H_∞ and 2-DOF H_∞ control schemes using triangular input signal	183
6.4	Performance measures of I- H_∞ and 2DOF H_∞ control schemes using specially generated input signal	184
7.1	Robust performance of the X Axis controlled system, δ_{vx} = 0.0006	202
7.2	Robust performance of the Y Axis controlled system, δ_{vx} = 0.004	202
7.3	Simulation results: the tracking performance for circular trajectory using different robust controllers	210
7.4	Tracking results for circular trajectories of the three designed robust controllers	213
7.5	Experimental tracking results for circular trajectory	217
7.6	Tracking error results for sinusoidal input signals	220
7.7	Tracking error results for triangular input signals	220

LIST OF FIGURES

Figure No.		Page No.
1.1	High precision positioning system	1
1.2	Flow chart of the research methodology	10
2.1	Different high precision positioning stages: X, XY, and XYZ axes	14
2.2	Stages for extremely precise positioning Systems	14
2.3	Controller structure with disturbance observer	19
2.4	Block diagram of a cross coupled motion-control system	25
2.5	Basic ILC configuration	28
2.6	T-S fuzzy reasoning	45
2.7	Architecture of an ANFIS equivalent to a first-order sugeno fuzzy model with two inputs and two rules	49
2.8	ANFIS learning using hybrid technique	49
3.1	DC motor driven rotary motion system (Quanser)	54
3.2	Elements of a single axis positioning stage	54
3.3	Simplified model of positioning stage	55
3.4	X-Y positioning system	57
3.5	Friction modelling, (a) Coulomb friction, (b) Viscous friction, (c) Stiction and (d) Total friction	62
3.6	Interfaces of frictional force between two surfaces: (a) Static state; (b) Presliding regime and (c) Sliding regime	65
3.7	Characteristic frictional force–velocity curve of the LuGre Model	66
3.8	Amplifier saturation model	68
3.9	Gear eccentricity	69

3.10	Gear backlash	69
3.11	Experimental set-up of the positioning servo system	73
3.12	(a) Input of PRBS and (b) Corresponding output signals of the identification experiment	73
3.13	Open loop response of the system to two different test signals: (a) Square and (b) PRBS.	74
3.14	Experimental friction characteristics	75
3.15	Experimental setup of the single axis positioning system	75
3.16	(a) Input PRBS and (b) Output signals of the identification experiment	76
3.17	(a) Input pulse and (b) Output Signals of the identification experiment	77
3.18	Simple measurement of time constant and gain of the positioning system	78
3.19	Real time xPC data collection	80
3.20	Experimental results of identification (a) Input PRBS signals applied for X axis only and (b) Output signals	80
3.21	Experimental results of identification (a) Input PRBS signals applied for Y axis only and (b) Output signals	81
3.22	Experimental results of identification (a) Input pulse signals applied for X axis only and (b) Output signals.	81
3.23	Experimental results of identification (a) Input pulse signals Applied for Y axis only and (b) Output signals.	81
4.1	Branches of control-relevant system identification	86
4.2	Block diagram of the servo motion system with uncertain parameters	93
4.3	Upper LFT representation of the system	95
4.4	Open loop frequency response characteristics for the Quansar servo system with parameters uncertainty	96
4.5	Plant with additive uncertainty	98

4.6 Plant with multiplicative uncertainty 98

4.7 Mixed additive- parametric uncertainty 98

4.8 Model error modelling diagram 106

4.9 Estimated model of model error $|G_e(j\omega)|$ using PEM within the MEM framework (a) Process model of two underdamped poles and zero, (b) Process model of two underdamped poles, zero and time delay 107

4.10 Different estimated model of model error $|G_e(j\omega)|$ using frequency fitting MEM framework (a) Higher range of frequencies, (b) Medium range of frequencies and (c) Lower range of frequencies 110

4.11 Different models of model error estimate $|G_e(j\omega)|$and residual using a 2Hz PRBS 110

4.12 Closed loop step responses of nominal H_∞ controlled system different models of model error $|G_e(j\omega)|$ to design the controller 112

4.13 Frequency response of the identified nominal model and the associated identified W_a within MEM 112

5.1 Intelligent model error identification using ANFIS 117

5.2 Intelligent model error identification using ANFIS in feedback 117

5.3 The entire-connection of the robustly-controlled system 126

5.4 Fuzzy models for identification of uncertainty bounds, showing inputs and outputs 128

5.5 Membership function plots of inputs of ANFIS1; $|G_e(j\omega)|$ and $|F(j\omega)|$ 129

5.6 ANFIS1 uncertainty bound and evaluated uncertainty function W_a 131

5.7 Experimental set-up of the positioning servo system 131

5.8 Measured output displacement step responses of the Quanser positioning system, using three designed H_∞ controllers 133

5.9 Measured control signals of three designed H_∞ controllers 133

5.10 Closed- loop step response of the controlled system after

	adding a load of 0.222 Kg	135
5.11	Membership function plots of inputs of ANFIS2; $\|G_e(j\omega)\|$ and $\|F(j\omega)\|$	136
5.12	ANFIS2 uncertainty bound and evaluated uncertainty weighting function W_a	136
5.13	Identified intelligent weighting function W_a using square input signal 5V p-p, 1Hz for closed loop identification, (a) Without control, (b) With *PV* control	139
5.14	A Plot showing different order uncertainty weighting functions W_a	140
5.15	Flowchart for the intelligent estimation of the uncertainty weighting function using ANFIS integrated with the robust controller design	143
5.16	Closed- loop step response of the motion system, using ANFIS1- W_a and ANFIS2- W_a for the controller design	144
5.17	Closed- loop step response of the motion system, using ANFIS2- W_a from PV closed loop controlled, and ANFIS2- W_a from closed loop uncontrolled, for the controller design	144
5.18	Identified intelligent weighting function W_a using sinusoidal input signal 5V p-p, 1Hz for closed- loop identification. (a) Without control, (b) With *PV* control	145
5.19	Identified intelligent weighting function W_a using sawtooth input signal 5V p-p, 1Hz for closed- loop identification (a) Without control, (b) With *PV* control	146
5.20	Closed-loop step response of the motion system using ANFIS2-W_a from closed-loop uncontrolled closed- loop system data, using Three Different Test Signals (Square, Sinusoidal, and Sawtooth) for the Controller Design	149
5.21	Identified intelligent weighting function W_a for AMB model, using CIN.	149
5.22	Identified intelligent weighting function W_a for AMB model, using ANFIS2	150
6.1	Plot of the sensitivity with and without H_∞ control against $1/\|W_e(j\omega)\|$	155

6.2	Flowchart for tuning the weighting functions, using constrained optimization	155
6.3	Standard feedback configuration	156
6.4	Open loop frequency response characteristics with parameters uncertainty	159
6.5	The closed-loop controlled system with structured uncertainties	159
6.6	Structure for robust stability analysis	160
6.7	μ plots of robust stability margins (inverted scale) of the robustly controlled system, considering structured parametric uncertainties	161
6.8	μ plots of robust stability margins (inverted scale) of the robustly controlled system, considering additive unstructured uncertainties	162
6.9	Structure for robust performance analysis	163
6.10	Robust performance μ plots of the robustly controlled system, considering structured parametric uncertainties	164
6.11	Robust performance μ plots of the robustly controlled system, considering additive unstructured uncertainties	164
6.12	Sensitivity function of the closed-loop robustly controlled system with $1/\|W_e(j\omega)\|$	167
6.13	Transient response of the closed- loop controlled system, using structured parametric uncertainty representation	167
6.14	Tracking error, using structured parametric uncertainty representation	168
6.15	Control signal, using structured parametric uncertainty representation	168
6.16	Transient response of the closed- loop controlled system, using structured parametric uncertainty representation	169
6.17	Tracking error, using structured parametric uncertainty representation	169
6.18	Control signal, using structured parametric uncertainty representation	170

6.19 ANFIS uncertainty bound and evaluated uncertainty function W_a 171

6.20 Sensitivity function of the closed- loop robustly controlled system with $1/|W_e(j\omega)|$ 172

6.21 Transient response of the closed- loop controlled system using unstructured additive uncertainty representation 174

6.22 Tracking error, using unstructured additive uncertainty representation 174

6.23 Control signal, using unstructured additive uncertainty representation 174

6.24 Transient response of the closed-loop controlled system, using unstructured additive uncertainty representation 175

6.25 Tracking error, using unstructured additive uncertainty representation 175

6.26 Control signal, using unstructured additive uncertainty representation 175

6.27 Integral-robust controller scheme 178

6.28 Transient response of the closed-loop controlled system, using optimized performance weighting function in the controller design 178

6.29 Block diagram of 2-DOF H_∞ controller 179

6.30 Solving the stability problem 180

6.31 Transient response of the closed-loop controlled system using Integral- H_∞ and 2-DOF H_∞ robust control 182

6.32 Transient response of the closed-loop controlled system using Integral- H_∞ and 2-DOF H_∞ robust controllers. A magnified plot from Figure 6.31 183

6.33 Tracking error, using Integral- H_∞ and 2-DOF H_∞ robust controller 183

6.34 Transient response of the closed- loop controlled system using 2-DOF H_∞ and integral- H_∞ robust controllers 184

6.35 Transient response of the closed- loop controlled system using 2-DOF H_∞ and integral-H_∞ robust controllers. Magnified plot 184

6.36 Tracking error, using 2-DOF H_∞ and integral- H_∞ robust controllers 185

7.1 Intelligent estimation of uncertainty and disturbance weighting function, using ANFIS 190

7.2 Standard feedback configuration with (a) Additive unstructured uncertainty and (b) The M-Δ structure 190

7.3 Frequency functions of the X and Y crosstalk 191

7.4 Standard feedback configuration 193

7.5 Position control with intelligent additive uncertainty and disturbance representation 195

7.6 Flow chart of the overall controller design 198

7.7 ANFIS uncertainty bound and evaluated uncertainty function W_a for (a) X-axis and (b) Y-axis 199

7.8 Estimated ANFIS disturbance and evaluated disturbance weighting function W_d for (a) X-axis and (b) Y-axis 201

7.9 Sensitivity functions of the closed-loop robustly controlled system for the X- axis 204

7.10 Sensitivity functions of the closed -loop robustly controlled System for the Y- axis 204

7.11 Complementary sensitivity sunctions of the closed-loop Robustly Controlled System for the X- axis 205

7.12 Complementary sensitivity functions of the closed- loop robustly controlled System for the Y- axis 205

7.13 Simulation results using PID controller 207

7.14 Simulation results using PID controller: Tracking errors of X and Y axes 207

7.15 Simulation results of the robustly controlled system using $H_{\infty 3}$(s) 207

7.16 Simulation results of the robustly controlled system using $H_{\infty 3}$(s), Tracking errors of X and Y axes 208

7.17 Simulation results using PID: (a) Resulted rhombus shape using triangular input signals and (b) Tracking errors 208

7.18 Simulation results of the robustly controlled system, (a) Resulted shape using triangular input signals and (b) Tracking errors of X and Y axes 209

7.19 Block diagram of the robust controlled two axes positioning system 212

7.20 Contour tracking errors for the three designed robust Controllers 212

7.21 Experimental results of PID control 213

7.22 Experimental results of PID control.Tracking errors for X and Y axes 213

7.23 Experimental results of PID control 215

7.24 Experimental results of H_∞ robustly controlled system 215

7.25 Experimental results of H_∞ robustly controlled system. Tracking errors for X and Y axes 215

7.26 Experimental results of H_∞ robustly controlled system. Contour tracking error 216

7.27 Experimental results of the intelligent robust control $H_{\infty 3}(s)$ 216

7.28 Experimental results of the intelligent robust control $H_{\infty 3}(s)$. Tracking errors for X and Y axes 216

7.29 Experimental results of the intelligent robust control $H_\infty(3)$. Contour tracking error 217

7.30 Experimental results of the PID controlled system 218

7.31 Experimental results of the PID controlled system. Tracking errors of X and Y axes 218

7.32 Experimental results of the intelligent robustly controlled system, using the $H_{\infty 3}(s)$ 219

7.33 Experimental results of the intelligent robustly controlled system, using the $H_{\infty 3}(s)$. Tracking errors of X and Y axes 219

7.34 System response using sinusoidal reference signals with frequency of 0.51 Hz, for X and Y axes 221

7.35 System response using sinusoidal reference signals with frequency of 0.80 Hz, for X and Y axes 221

7.36 System response using triangular reference signals with frequency of 2.0 Hz. (a) For X- axis, (b) For Y- axis 222

LIST OF ABBREVIATIONS

AFC	Adaptive Fuzzy Control
AFIS	Adaptive Fuzzy Inference Machine
ANFIS	Adaptive Neuro Fuzzy Inference System
ANN	Artificial Neural Network
AMB	Active Magnetic Bearings
AR	Auto Regressive
ARC	Adaptive Robust Control
ARMA	Auto Regressive Moving Average
ARMAX	Auto Regressive Moving Average with External Inputs
ARX	Auto Regressive with External Input
A/D	Analogue to Digital
CCC	Cross-Coupled Controller
CIN	Confidence Interval Network
CMM	Coordinate Measuring Machines
CNC	Computer Numerical Control
CNF	Composite Nonlinear Feedback
CP	Continuous- Path
DAQ	Data Acquisition System
DC	Direct Current
DFLS	Dynamic Fuzzy Logic System
DNLRX	Dynamic Nonlinear Regression with Direct Application of EXcitation

DOB	Disturbance Observer- Based
DDOB	Digital Disturbance Observer- Based
DOF	Degree Of Freedom
DRNN	Dynamic Recurrent Neural Network
DSP	Digital Signal Processor
D/A	Digital to Analogue
EDM	Electric Discharge Machining
emf	Electro-Motive Force
FNN	Fuzzy Neural Network
FIS	Fuzzy Inference Systems
FPE	Final Prediction Error
GIMC	Generalized Internal Model Control
GMS	Generalized Maxwell Slip
HPPS	High Precision Positioning System
IFOC	Indirect Flux Oriented Control
ILC	Iterative Learning Control
IMC	Internal Model Control
IPF	Intelligent Pre-shaping Filter
LBLDCM	Linear Brushless Direct Current Servo Motors
LFT	Linear Fractional Transformation
LMI	Linear Matrix Inequality
LPMSM	Linear Permanent Magnet Synchronous Motor
LUSM	Linear UltraSonic Motor
MEM	Model Error Modelling
MIMO	Multi-Input-Multi-Output