

WORLD SCIENTIFIC SERIES ON
NONLINEAR SCIENCE



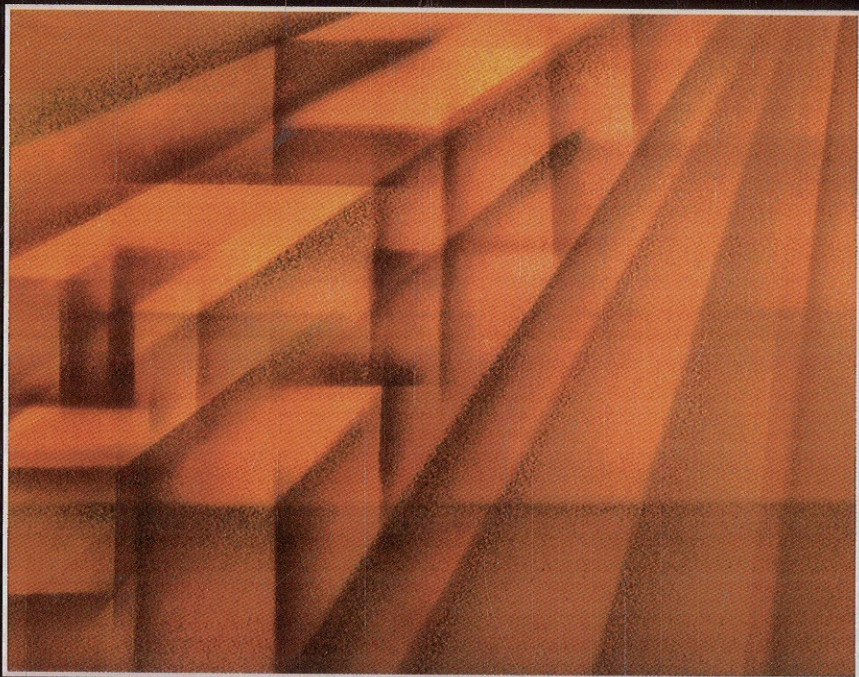
Series A Vol. 72

Series Editor: Leon O. Chua

FRACTIONAL ORDER SYSTEMS

Modeling and Control Applications

Riccardo Caponetto • Giovanni Dongola
Luigi Fortuna • Ivo Petráš



World Scientific

Contents

<i>Preface</i>	v
<i>Acknowledgments</i>	vii
<i>List of Figures</i>	xiii
<i>List of Tables</i>	xxi
1. Fractional Order Systems	1
1.1 Fractional Order Differintegral Operator: Historical Notes	1
1.2 Preliminaries and Definitions	2
1.3 Laplace Transforms and System Representation	4
1.4 General Properties of the Fractional System	6
1.5 Impulse Response of a General Fractional System	9
1.6 Numerical Methods for Calculation of Fractional Derivatives and Integrals	12
1.7 Fractional LTI Systems	16
1.8 Fractional Nonlinear Systems	20
1.9 Stability of Fractional LTI Systems	20
1.10 Stability of Fractional Nonlinear Systems	30
2. Fractional Order PID Controller and their Stability Regions Definition	33
2.1 Introduction	33
2.2 Problem Characterization	35
2.3 Theory for Analyzing Systems with Time Delays	36
2.3.1 Hermite-Biehler Theorem	37
2.3.2 Pontryagin Theorem	38

2.4	Stability Regions with $PI^\lambda D^\mu$ Controller	38
2.5	Results	41
3.	Fractional Order Chaotic Systems	53
3.1	Introduction	53
3.2	Concept of Chua's System	54
3.2.1	Classical Chua's Oscillator	54
3.2.2	Chua-Hartley's Oscillator	56
3.2.3	Chua-Podlubny's Oscillator	56
3.2.4	New Fractional-Order Chua's Oscillator	56
3.3	Fractional-Order Van der Pol Oscillator	59
3.4	Fractional-Order Duffing's Oscillator	60
3.5	Fractional-Order Lorenz's System	62
3.6	Fractional-Order Gencsio-Tesi System	65
3.7	Fractional-Order Lu's System	66
3.8	Fractional-Order Rossler's System	67
3.9	Fractional-Order Newton-Leipnik System	68
3.10	Fractional-Order Lotka-Volterra System	69
3.11	Concept of Volta's System	72
3.11.1	Integer-Order Volta's System	72
3.11.2	Fractional-Order Volta's System	73
4.	Field Programmable Gate Array Implementation	77
4.1	Numerical Fractional Integration	77
4.2	Grünwald-Letnikov Fractional Derivatives	78
4.3	The "Short-Memory" Principle	81
4.4	FPGA Hardware Implementation	82
4.4.1	FPGA Introduction	82
4.4.2	Remarks on the Fractional Differintegral Operator	83
4.4.3	FPGA Implementation of the Fractional Differintegral Operator	85
5.	Microprocessor Implementation and Applications	91
5.1	Introduction	91
5.2	Fractional Controller Realized by PIC Processor	98
5.2.1	Fractional-Order Integrator	99
5.2.2	Measured Results	99
5.3	Temperature Control of a Solid by PC and PCL 812	99

5.3.1	Model of Controlled System	99
5.3.2	Controller Parameters Design and Implementation	101
5.3.3	Experimental Setup and Results	104
5.4	Temperature Control of a Heater by PLC BR 2005	107
5.4.1	Model of Controlled System	107
5.4.2	Controller Parameters Design and Implementation	108
5.4.3	Experimental Setup and Results	110
5.5	Concluding Remarks	113
6.	Field Programmable Analog Array Implementation	115
6.1	The FPAAs Development System	115
6.2	Experimental Results	121
7.	Switched Capacitor Integrated Circuit Design	127
7.1	Introduction	127
7.2	Passive and Active Filters	128
7.3	Switched Capacitors Filters	129
7.4	Design of Sampled Data Filters	130
7.4.1	The Impulse Invariance Method	130
7.4.2	The Matched-z Transformation Method	131
7.4.3	Backward Euler Approximation of Derivatives . .	132
7.4.4	Forward Euler Approximation of Derivatives . . .	133
7.4.5	The Bilinear Transformation Method	134
7.4.6	The Lossless Discrete Integrator Transformation .	135
7.5	Switched Capacitor Fundamental Circuits	135
7.5.1	Resistor Realized by Backward Euler Transformation	136
7.6	Circuitual Implementation of the Fractional Order Integrator	136
7.7	Switched Capacitors Implementation of Fractional Order Integrator	139
7.8	Results	139
8.	Fractional Order Model of IPMC	145
8.1	Fractional Model Identification Introduction	145
8.2	Ionic Polymer Metal Composites (IPMC)	146
8.3	Actuation Mechanism on IPMCs	149
8.4	State-of-the-Art for IPMC Models	151

8.5	Experimental Setup	152
8.6	Marquardt Algorithm for the Least Squares Estimation .	155
8.7	Fractional Models for IPMC Actuators	158
8.7.1	Comparison Between an Integer Model and a Fractional Model of IPMC Actuators	158
8.7.2	Fractional Models for the Electrical and Electromechanical Stages of IPMC Actuators . . .	160
<i>Bibliography</i>		167
<i>Index</i>		177