

TABLE OF CONTENTS

	<u>Page</u>
PREFACE	iii
CONTROL THEORY AND ANALYTICAL MECHANICS <i>R.W. Brockett</i>	1
1. Introduction	1
1.1 Descriptive vs. Prescriptive Science	1
1.2 Why Control Theory and Mechanics?	4
1.3 Literature	6
2. Inputs, Outputs and States	7
2.1 Some Specific Examples	7
2.2 Inputs, Outputs and States	14
2.3 The Taylor Series in Function Space	16
3. Lagrangian and Hamiltonian Control Systems	23
3.1 Lagrange's Equations with Exogenous Variables	23
3.2 Hamiltonian Systems	24
3.3 An Aside on Controllability	26
3.4 Natural Outputs and Passivity	33
4. Mechanical Synthesis	38
4.1 Some Examples of Synthesis	38
4.2 The Synthesis Problem	43
Bibliography	46
THE DIFFERENTIAL-GEOMETRIC DUALITY BETWEEN CONTROLLABILITY AND OBSERVABILITY FOR NONLINEAR SYSTEMS <i>Arthur Krener and Robert Hermann</i>	49
1. Introduction	49
2. Controllability and Vector Fields	50
3. The Observability Pfaffian System	53
Bibliography	63

	<u>Page</u>
APPLICATIONS OF ALGEBRAIC GEOMETRY TO SYSTEMS THEORY, PART V: RAMIFICATIONS OF THE MACMILLAN DEGREE <i>Robert Hermann and Clyde Martin</i>	67
1. Introduction	67
2. Linear Time-Varying Systems and the Laplace Transform for Scalar Input-Output Systems	70
3. Feedback for Time-Varying Systems	77
4. The Properties of the Sheaf of all Input-Output Pairs as a Systems-Theoretic Invariant	79
5. The Solution Sheaf of a System Governed by First Order Equations	83
6. The Macmillan Degree in the Time Domain for Scalar Stationary Input-Output Systems	89
7. The Macmillan Degree for Weighting Patterns of Stationary Vector Input-Output Systems	95
8. A Realization of a Stationary Weighting Pattern in Terms of Solutions of Operator Differential Equations	104
9. Infinite Dimensional Linear Systems Defined by Infinite Order Differential Equations	109
10. A Topological Definition of the Macmillan Degree of the Weighting Pattern in the Time Domain	115
Bibliography	120
APPLICATIONS OF ALGEBRAIC GEOMETRY TO SYSTEMS THEORY, PART VI: INFINITE DIMENSIONAL LINEAR SYSTEMS AND PROPERTIES OF ANALYTIC FUNCTIONS <i>Clyde Martin and Robert Hermann</i>	121
1. Introduction	121
2. The Realization of Rational Functions as Transfer Functions in Terms of the Theory of Riemann Surfaces	124
3. Analytic Functions Defined by Cauchy Integral Formulas	132
4. Generalized Cauchy Integral Formulas	139
5. A New Form of the Transfer Function for Infinite Dimensional Linear Systems	141
6. Transfer Functions Defined by Ordinary Differ- ential Operators	144
Bibliography	155

AN INTRODUCTION TO CATASTROPHE THEORY

Hector J. Sussman

157

1. Introduction

157

2. The Main Mathematical Ideas

159

Bibliography

202

A SUMMARY OF THE PROCEEDINGS--SEMINAR/INSTITUTE ON
DIFFERENTIAL AND ALGEBRAIC GEOMETRY FOR CONTROL
ENGINEERS*Peter Crouch*

203

Purpose and Approach

203

Summary of Proceedings

206

Linear Systems

207

Input Output Descriptions

211

Mainstream Concepts

215

Applications

219

Research Needs

225

Conclusion

228

THE MODULI SPACE FOR LINEAR DYNAMICAL SYSTEMS

Christopher I. Byrnes

229

1. The Problem

230

2. The Space of Transfer Functions

235

3. The Affine Invariant Theory for Dynamical
Systems

239

4. The Geometric Invariant Theory of Dynamical
Systems

243

5. Applications of Geometric Invariant Theory to
Linear Dynamical Systems

255

6. The Algebraic Topology of the Moduli Space and
its Relation to Canonical Forms

259

Bibliography

275

REPRESENTATIONS OF QUIVERS AND MODULI OF LINEAR
DYNAMICAL SYSTEMS*Michiel Hazewinkel*

277

1. Preface

277

2. Quivers and their Representations

278

	<u>Page</u>
3. Gabriel's Theorem and its Relatives	281
4. On the Quivers of (Algebraic) Linear System Theory	284
Bibliography	287
 MODULI AND CANONICAL FORMS FOR LINEAR DYNAMICAL SYSTEMS, III: THE ALGEBRAIC-GEOMETRIC CASE	
<i>Michiel Hazewinkel</i>	291
1. Introduction	291
2. The Quotient Variety $M_{n,m,p}^{CR}$	297
3. The Fine Moduli Variety $M_{n,m,p}^{CR}$	318
4. Existence and Nonexistence of Algebraic Continuous Canonical Forms	322
Bibliography	335
 MULTILINEAR OPTIMAL CONTROL	
<i>John Baillieul</i>	337
1. Introduction	337
2. Multilinear Differential Equations	338
3. Optimal Control Theory for Multilinear Systems	344
4. Complete Solutions for the Case $p=1, q=0$	350
5. Conclusion	358
Bibliography	358
 TRANSVERSELY COMPLETE ϵ -FOLIATIONS OF CODIMENSION ONE AND ACCESSIBILITY PROPERTIES OF NON-LINEAR SYSTEMS	
<i>William M. Boothby</i>	361
1. Introduction	361
2. Foliations of Manifolds	365
3. An Application of Foliation Theory	372
4. Final Comments	381
Bibliography	384
 FINITE VOLTERRA SERIES	
<i>Peter Crouch</i>	387
1. Realizability	392
2. Structural Equations	394

3. The Lie Algebra and State Space	399
4. Conclusion	403
Bibliography	403

FOURIER-BOREL DUALITY AND BILINEAR REALIZATIONS OF CONTROL SYSTEMS

<i>Thomas A.W. Dwyer, III</i>	405
1. Bilinearization of Linear-Analytic Systems	407
2. Fourier-Borel Duality and Hyperdifferential Operators in Banach Spaces	413
3. The Ovcyannikov-Trèves Theorem and Bilinear Systems in Scales of Banach Spaces	420
4. Volterra Series for Linear-Analytic Systems in Banach Spaces	424
5. Cauchy Integral Formulas for the Volterra Kernels	427
6. Linear-Analytic Systems in Scales of Banach Spaces	428
7. Weighted Analytic Bilinearizations and Inverse Problems	429
8. Dual Pairs of Linear-Analytic Systems: Controllability and Observability	430
Bibliography	433

ACCESSIBILITY PROPERTIES OF SMOOTH NONLINEAR CONTROL SYSTEMS

<i>N. Kalouptsidis and D.L. Elliott</i>	439
1. Introduction	439
2. C^∞ Symmetric Systems	444
3. Controllable Systems	445
Bibliography	446

A NON-COMMUTATIVE SYMBOLIC CALCULUS FOR NON-LINEAR FUNCTIONALS AND AUTOMATIC CONTROL SYSTEMS

<i>Michel Fließ</i>	447
1. Notation	447
2. Rational Non-Commutative Formal Power Series	447
3. Regular (or Bilinear) Systems	449
4. Relation to Volterra Series--Approximation Results	450

Page

5. An Example of Symbolic Calculus: Forced Non-Linear Equations	451
Bibliography	454

PIECEWISE ANALYSIS OF LARGE LINEAR SYSTEMS: KRON'S METHOD AND SPARSE MATRIX PROCEDURES	
<i>B. Kent Harrison</i>	455
1. Introduction	455
2. Network Topology	456
3. Electrical Network Equations	459
4. Tearing and Interconnection	462
5. Sparse Matrix Procedures	469
Appendix	475
Bibliography	480

NORMAL FORMS FOR REAL LINEAR HAMILTONIAN SYSTEMS	
<i>N. Burgoyne and R. Cushman</i>	483
1. Real Linear Hamiltonian Differential Equations	484
2. Basic Symplectic Linear Algebra	487
3. Statement of Results	492
4. Proofs of the Propositions	497
5. An Algorithm for Finding the Normal Form	526
Appendix	527
Bibliography	528

MODELING AND ANALYSIS OF LINEAR SYSTEMS WITH MULTIPLICATIVE POISSON WHITE NOISE	
<i>Steven I. Marcus</i>	531
1. Introduction	531
2. The Poisson-Driven Canonical Extension	535
3. Moment Equations and Stochastic Stability	549
Bibliography	553