## CONTENT

1.	Introdu	uction	1	
	1-1	The Control Problem	1	
	1-2	Optimal Control versus Conventional Control	3	
	1-3	State-variable Formulation of the System Equations	5	
	1-4	The Index of Performance	11	
	1-5	The Control Function versus The Control Law	12	
	1-6	Suboptimal Control	13	
	1-7	Controllability and Observability	14	
	1-8	Summary	15	
	1-9			
2.	Forma	tive Concepts	17	
	2-1	Preliminary Remarks	17	
	2-2	Minima of Functions	17	
	2-3	One Independent Variable	19	
	2-4	Two Independent Variables	22	
	2-5	N Independent Variables	27	
	2-6	Constraint Equations	30	
	2-7	Minima of Definite Integrals – The Calculus of Variations	33	
	2-8	The Euler Equation	35	
	2-9	The Case $f = f(\mathbf{x}, \mathbf{x})$	40	
	2-10	The Weierstrass-Erdmann Corner Conditions	40	
	2-11	The Second Variation	43	
	2-12	The Extension to N System Variables	50	
	2-13	Differential Constraints Among the System Variables	55	
3	Develo	opment Through the Control Formulation	61	
5.	3_1	A More Realistic Problem	61	
	3_2	The First Variation	62	
	3_3	The Fuler (Characteristic) Equations	67	
	3_1	The Transversality Condition	68	
	3-5	The Results for N System Variables	71	
	3.6	The Weierstrass and Legendre Clebsch Conditions	80	
	3-0	Problems Not Involving Rates	86	
	3.8	The Results Expressed for Control applications	88	
	3_9	The Lunar Ascent Problem	92	
	5-9	The Lunai Ascent Problem	92	
4.	The Ex	xtension to Control-Variable Inequality Constraints	102	
	4-1	A Simple Linear Plant	102	
	4-2	Control of a Chemical Reactor	106	
	4-3	A Two-point Boundary-Value Problem	109	
	4-4	Control-Variable Inequality Constraints	112	
	4-5	An Alternative Formulation	119	
	4-6	The Weierstrass Condition with Control-Variable Inequality Constraints	121	
	4-7	The Chemical Reactor – Bounded Control	123	
	4-8	The Pure Inertia Plant	131	
5.	State-Variable Inequality Constraints			
	5-1	problems with Intermediate Conditions	139	
	5-2	State-Variable Inequality Constraints	143	
	5-3	Conditions for Problems with Discontinuous controls	146	
	5-4	An Exercise in Road Building	147	
	5-5	Toward Smoother Roads	152	

	5-6	A Minimum-Weight Beam	154
	5-7	A Minimum-Weight Beam – Solution Continued	159
6.	Direct Methods – The Technique of Steepest Descent		
	6-1	Introduction	167
	6-2	A Simple Example from the Minima of Functions	168
	6-3	The Treatment of Constraints	170
	6-4	Control Formulation	175
	6-5	The Case of n State Variables and m control Variables – Formulation	181
	6-6	The Case of n State Variables and m Control Variables – Solution	184
	6-7	The Adjoint Equations	188
	6-8	Application to the Minimization of a Functional – Formulation	193
	6-9	Solution of the Problem	199
	6-10	Application of the Technique to the Lunar Ascent Problem	202
	6-11	The Penalty-Function Approach	208
	6-12	Concluding Remarks	209
7.	Dynamic Programming and Optimal Control		
	7-1	The Optimal Allocation Problem	210
	7-2	Application to the Control Problem – Theory	216
	7-3	A Perfect Integrator	219
	7-4	The Computational Scheme	223
	7-5	Relation to the Calculus of Variations	229
	7-6	The Hamilton-Jacobi Equation	232
	7-7	Conclusions	233
8.	Optimal Feedback Control		
	8-1	Introduction	235
	8-2	Linear Systems with a Quadratic Performance Index – Formulation	236
	8-3	Linear Systems with a Quadratic Performance Index – Solution	238
	8-4	The Inertia Plant	242
	8-5	Implementation of the Solution	245
	8-6	A tutorial Example	248
	8-7	The Nonlinear Problem – A Guidance Solution	250
	8-8	A Transfer Problem	255

Index

263