

Contents

<i>Foreword</i>	<i>vii</i>
<i>Preface</i>	<i>ix</i>
<i>Acknowledgements</i>	<i>xiii</i>
1. Introduction	1
1.1 Engineering Design	1
1.2 Computer as an Aid to the Design Engineer	2
1.2.1 Computer as a Participant in a Design Team	2
1.3 Computer Graphics	3
1.3.1 Graphics Systems and Hardware	4
1.3.2 Input Devices	4
1.3.3 Display and Output Devices	5
1.4 Graphics Standards and Software	6
1.5 Designer-Computer Interaction	7
1.6 Motivation and Scope	8
1.7 Computer Aided Mechanism and Machine Element Design	12
Exercises	20
2. Transformations and Projections	23
2.1 Definition	24
2.2 Rigid Body Transformations	24
2.2.1 Rotation in Two-Dimensions	25
2.2.2 Translation in Two-Dimensions: Homogeneous Coordinates	25
2.2.3 Combined Rotation and Translation	27
2.2.4 Rotation of a Point $Q(x_q, y_q, 1)$ about a Point $P(p, q, 1)$	29
2.2.5 Reflection	29
2.2.6 Reflection About an Arbitrary Line	30
2.2.7 Reflection through a Point	31
2.2.8 A Preservative for Angles! Orthogonal Transformation Matrices	32
2.3 Deformations	34
2.3.1 Scaling	34
2.3.2 Shear	35
2.4 Generic Transformation in Two-Dimensions	36
2.5 Transformations in Three-Dimensions	37

2.5.1	Rotation in Three-Dimensions	37	
2.5.2	Scaling in Three-Dimensions	40	
2.5.3	Shear in Three-Dimensions	41	
2.5.4	Reflection in Three-Dimensions	41	
2.6	Computer Aided Assembly of Rigid Bodies	44	
2.7	Projections	48	
2.7.1	Geometry of Perspective Viewing	49	
2.7.2	Two Point Perspective Projection	53	
2.8	Orthographic Projections	54	
2.8.1	Axonometric Projections	55	
2.9	Oblique Projections	60	
	<i>Exercises</i>	62	
3.	Differential Geometry of Curves		66
3.1	Curve Interpolation	67	
3.2	Curve Fitting	70	
3.3	Representing Curves	73	
3.4	Differential Geometry of Curves	75	
	<i>Exercises</i>	82	
4.	Design of Curves		84
4.1	Ferguson's or Hermite Cubic Segments	87	
4.1.1	Composite Ferguson Curves	89	
4.1.2	Curve Trimming and Re-parameterization	94	
4.1.3	Blending of Curve Segments	96	
4.1.4	Lines and Conics with Ferguson Segments	97	
4.1.5	Need for Other Geometric Models for the Curve	100	
4.2	Three-Tangent Theorem	101	
4.2.1	Generalized de Casteljau's Algorithm	101	
4.2.2	Properties of Bernstein Polynomials	103	
4.3	Barycentric Coordinates and Affine Transformation	106	
4.4	Bézier Segments	107	
4.4.1	Properties of Bézier Segments	109	
4.4.2	Subdivision of a Bézier Segment	113	
4.4.3	Degree-Elevation of a Bézier Segment	116	
4.4.4	Relationship between Bézier and Ferguson Segments	117	
4.5	Composite Bézier Curves	118	
4.6	Rational Bézier Curves	121	
	<i>Exercises</i>	127	
5.	Splines		130
5.1	Definition	130	
5.2	Why Splines?	132	
5.3	Polynomial Splines	132	
5.4	B-Splines (Basis-Splines)	136	
5.5	Newton's Divided Difference Method	138	
5.5.1	Divided Difference Method of Compute B-Spline Basis Functions	141	
5.6	Recursion Relation to Compute B-Spline Basis Functions	143	
5.6.1	Normalized B-Spline Basic Functions	145	

5.7	Properties of Normalized B-Spline Basis Functions	146
5.8	B-Spline Curves: Definition	151
5.8.1	Properties of B-Spline Curves	152
5.9	Design Features with B-Spline Curves	155
5.10	Parameterization	158
5.10.1	Knot Vector Generation	159
5.11	Interpolation with B-Splines	160
5.12	Non-Uniform Rational B-Splines (NURBS)	161
	<i>Exercises</i>	162
6.	Differential Geometry of Surfaces	165
6.1	Parametric Representation of Surfaces	166
6.1.1	Singular Points and Regular Surfaces	168
6.1.2	Tangent Plane and Normal Vector on a Surface	169
6.2	Curves on a Surface	171
6.3	Deviation of the Surface from the Tangent Plane: Second Fundamental Matrix	173
6.4	Classification of Points on a Surface	175
6.5	Curvature of a Surface: Gaussian and Mean Curvature	178
6.6	Developable and Ruled Surfaces	181
6.7	Parallel Surfaces	185
6.8	Surfaces of Revolution	188
6.9	Sweep Surfaces	190
6.10	Curve of Intersection between Two Surfaces	193
	<i>Exercises</i>	197
7.	Design of Surfaces	201
7.1	Tensor Product Surface Patch	202
7.1.1	Ferguson's Bi-cubic Surface Patch	203
7.1.2	Shape Interrogation	206
7.1.3	Sixteen Point Form Surface Patch	210
7.1.4	Bézier Surface Patches	211
7.1.5	Triangular Surface Patch	216
7.2	Boundary Interpolation Surfaces	218
7.2.1	Coon's patches	219
7.3	Composite Surfaces	226
7.3.1	Composite Ferguson's Surface	226
7.3.2	Composite Bézier Surface	229
7.4	B-Spline Surface Patch	241
7.5	Closed B-Spline Surface	243
7.6	Rational B-spline Patches (NURBS)	244
	<i>Exercises</i>	245
8.	Solid Modeling	247
8.1	Solids	247
8.2	Topology and Homeomorphism	249
8.3	Topology of Surfaces	251
8.3.1	Closed-up Surfaces	251
8.3.2	Some Basic Surfaces and Classification	252

8.4	Invariants of Surfaces	254	
8.5	Surfaces as Manifolds	255	
8.6	Representation of Solids: Half Spaces	256	
8.7	Wireframe Modeling	257	
8.8	Boundary Representation Scheme	259	
8.8.1	Winged-Edge Data Structure	259	
8.8.2	Euler-Poincaré Formula	261	
8.8.3	Euler-Poincaré Operators	263	
8.9	Constructive Solid Geometry	265	
8.9.1	Boolean Operations	267	
8.9.2	Regularized Boolean Operations	268	
8.10	Other Modeling Methods	269	
8.11	Manipulating Solids	271	
	<i>Exercises</i>	273	
9.	Computations for Geometric Design		275
9.1	Proximity of a Point and a Line	275	
9.2	Intersection Between Lines	277	
9.2.1	Intersection Between Lines in Three-dimensions	279	
9.3	Relation Between a Point and a Polygon	280	
9.3.1	Point in Polygon	280	
9.4	Proximity Between a Point and a Plane	282	
9.4.1	Point within a Polyhedron	285	
9.5	Membership Classification	286	
9.6	Subdivision of Space	286	
9.6.1	Quadtree Decomposition	287	
9.7	Boolean Operations on Polygons	290	
9.8	Inter Section Between Free Form Curves	292	
	<i>Exercises</i>	293	
10.	Geometric Modeling Using Point Clouds		295
10.1	Reverse Engineering and its Applications	295	
10.2	Point Cloud Acquisition	296	
10.3	Surface Modeling from a Point Cloud	297	
10.4	Meshed or Faceted Models	298	
10.5	Planar Contour Models	299	
10.5.1	Points to Contour Models	299	
10.6	Surface Models	301	
10.6.1	Segmentation and Surface Fitting for Prismatic Objects	303	
10.6.2	Segmentation and Surface Fitting for Freeform Shapes	305	
10.7	Some Examples of Reverse Engineering	308	
11.	Finite Element Method		309
11.1	Introduction	309	
11.2	Springs and Finite Element Analysis	310	
11.3	Truss Elements	313	
11.3.1	Transformations and Truss Element	315	

11.4	Beam Elements	318	
11.5	Frame elements	322	
11.5.1	Frame Elements and Transformations	324	
11.6	Continuum Triangular Elements	325	
11.7	Four-Node Elements	331	
	<i>Exercises</i>	336	
12.	Optimization		339
12.1	Classical Optimization	339	
12.2	Single Variable Optimization	339	
12.2.1	Bracketing Methods	340	
12.2.2	Open Methods	345	
12.3	Multivariable Optimization	348	
12.3.1	Classical Multivariable Optimization	348	
12.3.2	Constrained Multivariable Optimization	349	
12.3.3	Multivariable Optimization with Inequality Constraints	353	
12.3.4	Karush-Kuhn-Tucker (KKT) Necessary Conditions for Optimality	355	
12.4	Linear Programming	359	
12.4.1	Simple Method	360	
12.5	Sequential Linear Programming (SLP)	363	
12.6	Sequential Quadratic Programming (SQP)	364	
12.7	Stochastic Approaches (Genetic Algorithms and Simulated Annealing)	365	
	<i>Exercises</i>	368	
	Appendix: Mesh Generation		370
	Suggested Projects		378
	Bibliography		385
	Index		389

Computer Aided Engineering Design