
Contents

Preface	xiii
1 Introduction	1
1-1 Definition of Photogrammetry	1
1-2 History of Photogrammetry	2
1-3 Types of Photographs	3
1-4 Taking Vertical Aerial Photographs	8
1-5 Existing Aerial Photography	10
1-6 Uses of Photogrammetry	11
1-7 Photogrammetry and Geographic Information Systems	13
1-8 Professional Photogrammetry Organizations	14
References	15
Problems	16
2 Principles of Photography and Imaging	19
2-1 Introduction	19
2-2 Fundamental Optics	20
2-3 Lenses	23
2-4 Single-Lens Camera	28
2-5 Illuminance	29
2-6 Relationship of Aperture and Shutter Speed	30
2-7 Characteristics of Photographic Emulsions	33
2-8 Processing and Printing Black-and-White Photographs	36
2-9 Spectral Sensitivity of Emulsions	39
2-10 Filters	41
2-11 Color Film	42
2-12 Digital Images	44
2-13 Color Image Representation	49
2-14 Digital Image Display	55
References	56
Problems	57
3 Cameras and Other Imaging Devices	61
3-1 Introduction	61
3-2 Metric Cameras for Aerial Mapping	62

3-3	Main Parts of Frame Aerial Cameras	65
3-4	Focal Plane and Fiducial Marks	67
3-5	Shutters	69
3-6	Camera Mounts	70
3-7	Camera Controls	72
3-8	Automatic Data Recording	72
3-9	Digital Mapping Cameras	73
3-10	Camera Calibration	78
3-11	Laboratory Methods of Camera Calibration	82
3-12	Stellar and Field Methods of Camera Calibration	85
3-13	Calibration of Nonmetric Cameras	86
3-14	Calibrating the Resolution of a Camera	87
	References	91
	Problems	92

4	Image Measurements and Refinements	95
4-1	Introduction	95
4-2	Coordinate Systems for Image Measurements	95
4-3	Simple Scales for Photographic Measurements	97
4-4	Measuring Photo Coordinates with Simple Scales	98
4-5	Comparator Measurement of Photo Coordinates	98
4-6	Photogrammetric Scanners	99
4-7	Refinement of Measured Image Coordinates	100
4-8	Distortions of Photographic Films and Papers	101
4-9	Image Plane Distortion	101
4-10	Reduction of Coordinates to an Origin at the Principal Point	103
4-11	Correction for Lens Distortions	104
4-12	Correction for Atmospheric Refraction	109
4-13	Correction for Earth Curvature	113
4-14	Measurement of Feature Positions and Edges	113
	References	115
	Problems	116

5	Object Space Coordinate Systems	119
5-1	Introduction	119
5-2	Concepts of Geodesy	119
5-3	Geodetic Coordinate System	122
5-4	Geocentric Coordinates	124
5-5	Local Vertical Coordinates	124
5-6	Map Projections	126
5-7	Horizontal and Vertical Datums	131
	References	135
	Problems	136
 6	 Vertical Photographs	 137
6-1	Geometry of Vertical Photographs	137
6-2	Scale	138
6-3	Scale of a Vertical Photograph Over Flat Terrain	139
6-4	Scale of a Vertical Photograph Over Variable Terrain	140
6-5	Average Photo Scale	141
6-6	Other Methods of Determining Scale of Vertical Photographs	145
6-7	Ground Coordinates from a Vertical Photograph	146
6-8	Relief Displacement on a Vertical Photograph	149
6-9	Flying Height of a Vertical Photograph	152
6-10	Error Evaluation	154
	References	156
	Problems	156
 7	 Stereoscopic Viewing	 161
7-1	Depth Perception	161
7-2	The Human Eye	162
7-3	Stereoscopic Depth Perception	163
7-4	Viewing Photographs Stereoscopically	164
7-5	Stereoscopes	167
7-6	The Use of Stereoscopes	171
7-7	Causes of Y Parallax	174
7-8	Vertical Exaggeration in Stereoviewing	175
	References	180
	Problems	181

8	Stereoscopic Parallax	183
8-1	Introduction	183
8-2	Photographic Flight-Line Axes for Parallax Measurement	185
8-3	Monoscopic Methods of Parallax Measurement	187
8-4	Principle of the Floating Mark	188
8-5	Stereoscopic Methods of Parallax Measurement	191
8-6	Parallax Equations	193
8-7	Elevations by Parallax Differences	196
8-8	Simplified Equation for Heights of Objects from Parallax Differences	198
8-9	Measurement of Parallax Differences	199
8-10	Computing Flying Height and Air Base ...	201
8-11	Error Evaluation	202
	References	204
	Problems	204
9	Elementary Methods of Planimetric Mapping for GIS	209
9-1	Introduction	209
9-2	Planimetric Mapping with Reflection Instruments	210
9-3	Georeferencing of Digital Imagery	211
9-4	Heads-Up Digitizing	219
9-5	Photomaps	219
9-6	Mosaics	221
9-7	Uncontrolled Digital Mosaics	222
9-8	Semiconrolled Digital Mosaics	225
9-9	Controlled Digital Mosaics	228
	References	230
	Problems	230
10	Tilted and Oblique Photographs	233
10-1	Introduction	233
10-2	Point Perspective	234
10-3	Angular Orientation in Tilt, Swing, and Azimuth	236
10-4	Auxiliary Tilted Photo Coordinate System	238
10-5	Scale of a Tilted Photograph	239
10-6	Relief Displacement on a Tilted Photograph	242

10-7	Determining the Angle of Inclination of the Camera Axis in Oblique Photography	242
10-8	Computing Horizontal and Vertical Angles from Oblique Photos	246
10-9	Angular Orientation in Omega-Phi-Kappa	247
10-10	Determining the Elements of Exterior Orientation	249
10-11	Rectification of Tilted Photographs	249
10-12	Correction for Relief of Ground Control Points Used in Rectification	251
10-13	Analytical Rectification	253
10-14	Optical-Mechanical Rectification	254
10-15	Digital Rectification	256
10-16	Atmospheric Refraction in Tilted Aerial Photographs	257
	References	262
	Problems	263
11	Introduction to Analytical Photogrammetry	267
11-1	Introduction	267
11-2	Image Measurements	267
11-3	Control Points	268
11-4	Collinearity Condition	268
11-5	Coplanarity Condition	270
11-6	Space Resection by Collinearity	271
11-7	Space Intersection by Collinearity	273
11-8	Analytical Stereomodel	276
11-9	Analytical Interior Orientation	276
11-10	Analytical Relative Orientation	277
11-11	Analytical Absolute Orientation	284
	References	286
	Problems	286
12	Stereoscopic Plotting Instruments	291
12-1	Introduction	291
12-2	Classification of Stereoscopic Plotters	293
	PART I DIRECT OPTICAL PROJECTION STEREOPLOTTERS	
12-3	Components	294
12-4	Projection Systems	295
12-5	Viewing and Tracing Systems	296
12-6	Interior Orientation	298

12-7	Relative Orientation	298
12-8	Absolute Orientation	299
PART II ANALYTICAL PLOTTERS		
12-9	Introduction	302
12-10	System Components and Method of Operation	303
12-11	Analytical Plotter Orientation	305
12-12	Three-Dimensional Operation of Analytical Plotters	308
12-13	Modes of Use of Analytical Plotters	310
PART III SOFTCOPY PLOTTERS		
12-14	Introduction	311
12-15	System Hardware	312
12-16	Image Measurements	316
12-17	Orientation Procedures	317
12-18	Epipolar Geometry	317
	References	319
	Problems	319
13	Topographic Mapping and Spatial Data Collection	321
13-1	Introduction	321
13-2	Direct Compilation of Planimetric Features by Stereoplotter	322
13-3	Direct Compilation of Contours by Stereoplotter	323
13-4	Digitizing Planimetric Features from Stereomodels	324
13-5	Representing Topographic Features in Digital Mapping	326
13-6	Digital Elevation Models and Indirect Contouring	327
13-7	Automatic Production of Digital Elevation Models	330
13-8	Orthophoto Generation	332
13-9	Map Editing	335
	References	338
	Problems	338
14	Laser Scanning Systems	341
14-1	Introduction	341
14-2	Principles and Hardware	342

14-3	Airborne Laser Scanning	344
14-4	Terrestrial Laser Scanning	346
14-5	Laser Scan Data	348
14-6	Error Evaluation	350
	References	351
	Problems	351
15	Fundamental Principles of Digital Image Processing	353
15-1	Introduction	353
15-2	The Digital Image Model	354
15-3	Spatial Frequency of a Digital Image	355
15-4	Contrast Enhancement	357
15-5	Spectral Transformations	359
15-6	Moving Window Operations	365
15-7	Multiscale Representation	372
15-8	Digital Image Matching	375
15-9	Summary	385
	References	385
	Problems	386
16	Control for Aerial Photogrammetry	389
16-1	Introduction	389
16-2	Ground Control Images and Artificial Targets	392
16-3	Number and Location of Photo Control ...	396
16-4	Traditional Field Survey Methods for Establishing Horizontal and Vertical Control	398
16-5	Fundamentals of the Global Positioning System	399
16-6	Kinematic GPS Positioning	403
16-7	Inertial Navigation Systems	405
16-8	GPS-INS Integration	407
	References	409
	Problems	409
17	Aerotriangulation	411
17-1	Introduction	411
17-2	Pass Points for Aerotriangulation	413
17-3	Fundamentals of Semianalytical Aerotriangulation	414
17-4	Sequential Construction of a Strip Model from Independent Models	414
17-5	Adjustment of a Strip Model to Ground ...	416
17-6	Simultaneous Bundle Adjustment	422

17-7	Initial Approximations for the Bundle Adjustment	430
17-8	Bundle Adjustment with Airborne GPS Control	433
17-9	Interpretation of Bundle Adjustment Results	437
17-10	Aerotriangulation with Airborne Linear Array Sensors	440
17-11	Satellite Image Triangulation	443
17-12	Efficient Computational Strategies for Aerotriangulation	446
	References	452
	Problems	453
18	Project Planning	457
18-1	Introduction	457
18-2	Importance of Flight Planning	458
18-3	Photographic End Lap and Side Lap	459
18-4	Purpose of the Photography	462
18-5	Photo Scale	464
18-6	Flying Height	468
18-7	Ground Coverage	470
18-8	Weather Conditions	471
18-9	Season of the Year	472
18-10	Flight Map	473
18-11	Specifications	478
18-12	Cost Estimating and Scheduling	480
	References	481
	Problems	481
19	Terrestrial and Close-Range Photogrammetry	485
19-1	Introduction	485
19-2	Applications of Terrestrial and Close-Range Photogrammetry	486
19-3	Terrestrial Cameras	488
19-4	Matrix Equations for Analytical Self-Calibration	490
19-5	Initial Approximations for Least Squares Adjustment	494
19-6	Solution Approach for Self-Calibration Adjustment	497
19-7	Control for Terrestrial Photogrammetry ...	498
19-8	Analytical Self-Calibration Example	500
19-9	Planning for Close-Range Photogrammetry	505

References	508
Problems	509
20 Photogrammetric Applications in GIS	511
20-1 Introduction	511
20-2 Land and Property Management	512
20-3 Floodplain Rating	513
20-4 Water Quality Management	515
20-5 Wildlife Management	519
20-6 Environmental Monitoring	522
20-7 Wetland Analysis	524
20-8 Transportation	525
20-9 Multipurpose Land Information System	527
20-10 Summary	528
References	528
Problems	530
A Units, Errors, Significant Figures, and Error Propagation	531
B Introduction to Least Squares Adjustment	541
C Coordinate Transformations	559
D Development of Collinearity Condition Equations	609
E Digital Resampling	627
F Conversions Between Object Space Coordinate Systems	635
Index	659