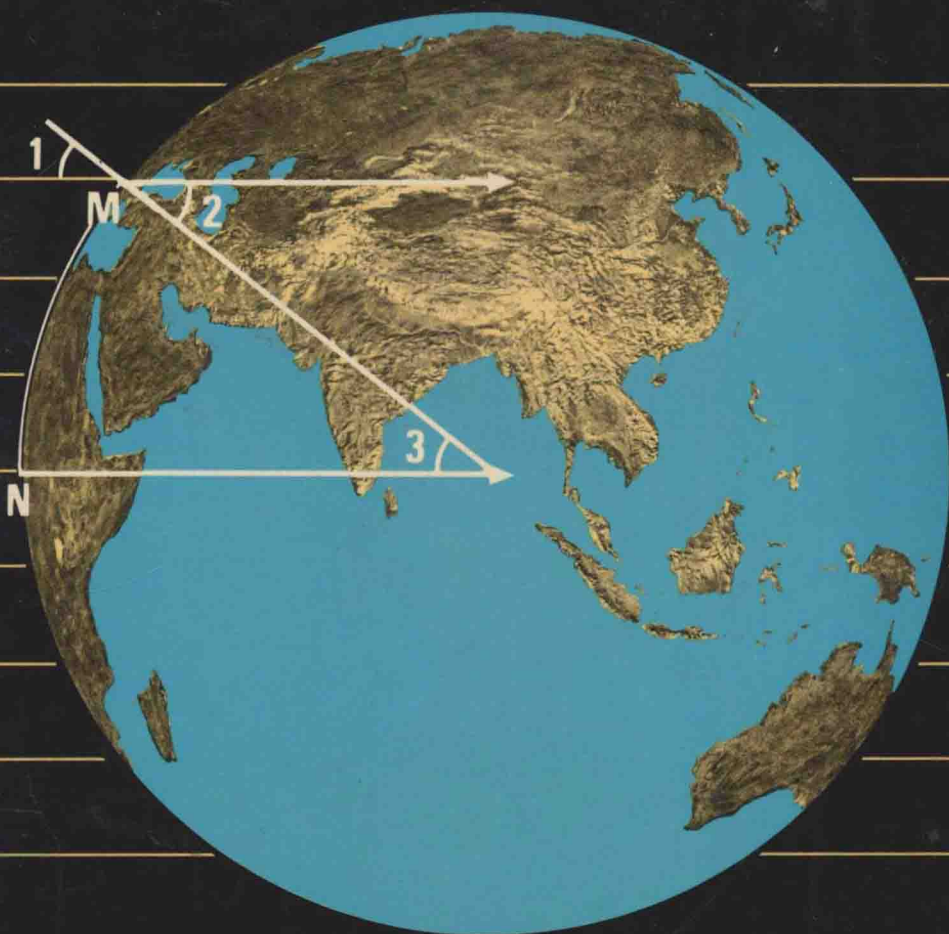


INTRODUCTION TO **SURVEYING**

IVAN I. MUELLER/KARL H. RAMSAYER



INTRODUCTION TO

SURVEYING

Ivan I. Mueller

*Professor, Department of Geodetic Science
The Ohio State University*

Karl H. Ramsayer

*Prof. Dr.-Ing. Dr.-Ing. E.h.
Geodätisches Institut
Universität Stuttgart*

Frederick Ungar Publishing Co. / New York

Copyright © 1979 by Frederick Ungar Publishing Co., Inc.
Printed in the United States of America
Designed by Stanley Rice

LC 79-4835
ISBN 0-8044-4666-0

ABOUT THE AUTHORS

DR. IVAN I. MUELLER is a professor in the Department of Geodetic Science, The Ohio State University. He is the current chairman of the Committee on Geodesy of the U.S. National Academy of Sciences. Among his many papers and several books are the well-received *Introduction to Satellite Geodesy* and *Spherical and Practical Astronomy as Applied to Geodesy*. He is editor of *Bulletin Geodesique*, Paris, and chairman of the editorial board of *Manuscripta Geodaetica*, Berlin. In 1976 he received the Humboldt Prize from the Alexander von Humboldt Foundation in Bonn, and in 1978 was elected Fellow of the American Geophysical Union.

DR. KARL H. RAMSAYER is a professor at the University of Stuttgart, FRG, and director of the Institutes of Geodesy and Navigation. A member of the German Geodetic Commission, he is corresponding member of the Austrian Academy of Sciences. He received an honorary doctorate from the University of Bonn in 1976 and was elected Fellow of the Royal Institute of Navigation, London, in 1974. He is the author of many publications in plane surveying, geodesy, and navigation.

INTRODUCTION TO
SURVEYING

ACKNOWLEDGMENTS

The origin of this book is in the booklet *Grundriss der Vermessungskunde* by Ramsayer, published in 1955 by Verlag Konrad Wittwer in Stuttgart. It was translated into English in 1975 by Alfred Leick and updated by Mueller. A preliminary version was reproduced in the form of lecture notes for the use of students in the Bachelor of Science programs in Surveying and Civil Engineering at The Ohio State University in 1975. Sections 2 through 4.1, 4.3, and 5 are based on the above work by Ramsayer, while the rest of the material is new. The use of the original material for this book was agreed upon between the two publishers.

Section 6.3 was written by Professor H. J. Steward, and 6.4 by Professor Olin Mintzer. Their contributions are gratefully acknowledged. Credit is given to D. Reidel Publishing Company and to Pergamon Press for the use of two articles by Mueller in Sections 4.42 and 6.1, originally published in *Geophysical Surveys* and in the *International Dictionary of Geophysics*, respectively. Credit for certain illustrations is due the following organizations: Kern Instruments, Inc., Brewster, New York 10509, for Fig. 3.1-3 through 3.1-6, 3.1-28, 3.1-38, 3.2-4, 3.3-2, 4.2-15. AGA Corporation, Geodimeter Division, San Rafael, California 94903, for Fig. 3.1-13. Wild Heerbrugg Instruments Inc., Farmingdale, L.I., New York 11735, for Figs. 3.1-29, 3.1-36, 3.1-39, 3.1-47, 3.2-3, 3.2-5, 3.2-6, 3.2-9, 3.4-2, 3.4-3, 3.4-6-3.4-8, 4.2-10, 4.2-11, 4.2-15. Credit for other illustrative material is given at the appropriate locations.

The authors are thankful to the publisher for his patience and cooperation, to Irene Tesfai for her work in producing the manuscript, to Lydia Bock for preparing the illustrations, and to Yehuda Bock, John Hannah, and Erricos Pavlis, graduate students in the Department of Geodetic Science, OSU, for help in proofreading and preparing the index.

November, 1978

Ivan I. Mueller Karl Ramsayer

INTRODUCTION TO
SURVEYING

CONTENTS

1 INTRODUCTION 1

- 1.1 Functions of Modern Surveyors 1
- 1.2 Opportunities for Surveyors 2
- 1.3 General Areas of Surveying 3
- 1.4 Units Used in the Book 4
- 1.5 The Purpose of This Book 5

2 NATURE OF ERRORS AND MEASUREMENTS 7

- 2.1 Measuring Error 7
- 2.2 Measure of Accuracy 9
- 2.3 Error Propagation 10
- 2.4 Measure of Precision 11
 - 2.41 The Simple Arithmetic Mean 11
 - 2.42 Weight of Measurement 12
 - 2.43 Weighted Arithmetic Mean 13

3 PLANE SURVEYING 14

- 3.1 Horizontal Surveying 14
 - 3.11 Horizontal Survey without Theodolite 14
 - 3.111 Marking of Points 14
 - 3.112 Simple Instruments for Setting Out Angles of 90° and 180° 14
 - 3.113 Setting out Straight Lines and Right Angles 17
 - 3.114 Distance Measurement with Chains, Rods, and Tapes 19
 - 3.115 Simple Survey of Lots and Buildings 22
 - 3.116 Simple Survey of Planimetric Map 24
 - 3.12 Electromagnetic Distance Measurement (EDM) 25
 - 3.121 General 25
 - 3.122 Electro-Optical Distance Measuring 25

	3.123	Microwave Distance Measuring	26
3.13		Area and Coordinate Computations	26
	3.131	Area Computation from Field Measurements	26
	3.132	Graphical and Semigraphical Area Computations	32
	3.133	Coordinate Transformation, Intersection of Lines	35
	3.134	Partitioning of Areas	38
3.14		Horizontal Survey with Theodolite	39
	3.141	Introduction	39
	3.142	The Theodolite	41
	3.143	Horizontal Angle Measurement	46
	3.144	Vertical Angle Measurement	52
	3.145	Optical Distance Measurement	53
	3.146	Trigonometric Point Determination	58
	3.147	Point Determination by Traverse	64
	3.148	Radial Surveys	68
3.2		Vertical Surveying (Height Measurement)	69
	3.21	Preview	69
	3.22	Geometric Leveling	70
	3.221	The Level and Leveling Staff	70
	3.222	The Method of Geometric Leveling	71
	3.223	Precise Leveling	77
	3.224	Application of Geometric Leveling	78
	3.23	Trigonometric Leveling	79
	3.24	Tacheometric Leveling	81
	3.25	Barometric Leveling	81
3.3		Combined Planimetry and Height Measurement	85
	3.31	Preview	85
	3.32	Tacheometry by Theodolite	86
	3.33	Tacheometry by Compass or Gyro-Theodolite	86
	3.34	Tacheometry by Plane Table	88
	3.35	Plotting of Contour Maps	89
3.4		Photogrammetry	90
3.5		Setting Out	101
4		GEODETIC SURVEYING	103
	4.1	Geometric Geodesy	104
		4.11 Preview	104
		4.12 Triangulation and Trilateration	108
		4.121 Methods	108
		4.122 Condition Equations	112
	4.13	Base Line Measurement and Extension	115
		4.131 Base Line Measurement	115
		4.132 Base Line Extension	116

4.14	Computations on the Sphere	116
4.141	Solving a Spherical Triangle	117
4.142	Orthogonal Spherical (Soldner) Coordinates	118
4.143	Projecting the Sphere onto the Plane	121
4.15	Computations on the Ellipsoid	123
4.151	Geodetic Coordinates and the Geodetic Datums	123
4.152	Plane Coordinates	125
4.2	Geodetic Astronomy	126
4.21	The Celestial Sphere and its Coordinate Systems	127
4.211	Definitions	127
4.212	Celestial Coordinate Systems	130
4.22	Transformation of Coordinates	132
4.221	Conversion between the Horizon and Hour Angle Systems	132
4.222	Conversions between the Hour Angle and Right Ascension Systems	135
4.23	Principles of Astronomic Positioning	136
4.231	Azimuth Determination	136
4.232	Latitude Determination	138
4.233	Time and Longitude	139
4.24	Instruments of Geodetic Astronomy	141
4.3	Determination of the Reference Surfaces and Gravimetric Geodesy	145
4.31	Geometric Methods	145
4.311	Geometric Determination of the Reference Ellipsoid	145
4.312	Geometric (Astro-geodetic) Determination of the Shape of the Geoid	148
4.32	Gravimetric Geodesy	151
4.321	Equipotential (Level) Surfaces and Gravity	151
4.322	Measurement of Gravity	153
4.323	Normal Gravity and Gravity Anomaly	156
4.324	Determination of the Geoid from Gravity Measurements	157
4.325	Comments on Geometric Leveling, Trigonometric Leveling and the Geoid	158
4.4	Modern Cartesian Three Dimensional Geodesy	162
4.41	Preview	162
4.42	Satellite Geodesy	164
4.421	Introduction	164
4.422	Principal Methods	165
4.423	Applications of Satellite Derived Geodetic Positions	175

4.424	Special Satellite Geodetic Techniques	180
4.425	Lunar Laser Ranging	181
4.43	Long Baseline Microwave Interferometry	186
4.431	Introduction	186
4.432	Basic Instrumentation	186
4.433	Applications	189
4.44	Inertial Survey Systems	191
4.441	Introduction	191
4.442	Various Systems	191
4.443	Survey Operations	192
5	ADJUSTMENT COMPUTATION BY LEAST SQUARES	194
5.1	Preview	194
5.2	Adjustment of Direct Observations	195
5.3	Adjustment by Observation Equations	196
5.4	Adjustment by Condition Equations	200
6	CARTOGRAPHY AND REMOTE SENSING	204
6.1	Map Projections	204
6.11	Introduction	204
6.12	Classification	205
6.13	Distortion	206
6.131	Direction and Angular Distortions	207
6.132	Length Distortion	208
6.133	Area Distortion	208
6.134	The Parameters of the Tissot Indicatrix	208
6.14	Projections of the Sphere	209
6.141	Conic Projections	210
6.142	Cylindric Projections	212
6.143	Azimuthal Projections	215
6.144	Polyconic Projections	217
6.15	Projection of a Rotational Ellipsoid on the Sphere	219
6.2	Plane Rectangular Coordinate Systems in the United States	220
6.21	State Plane Coordinate Systems	220
6.22	The United States System of Rectangular Surveys for Public Land	224
6.3	The Art and Science of Cartography	225
6.31	Introduction	225
6.32	Analyzing the Scope and Nature of Cartography	227
6.321	Cartography in Terms of Fundamental Conceptual and Practical Activities	227
6.322	Cartography in Terms of Map Products	228

6.323	Cartography in Terms of Information	230
6.324	Cartography in Terms of a Simple Division	231
6.33	Some Current Topics in Cartography	231
6.331	Automation	231
6.332	Perception	232
6.333	Photomapping	232
6.34	Summary	232
6.4	Remote Sensing	233
6.41	Introduction	233
6.42	Aerial Color and Color Infrared Photography and Photo Interpretation	233
6.43	Geophysical Surveys and Combinations of Techniques	234
6.44	Side Looking Radar (SLAR)	234
6.45	Infrared Principles, Detection and Imagery	235
6.46	Multispectral Techniques	237
6.47	Earth Resources Technology Satellite	238
6.48	Summary	239
Appendix 1	Selected Pages from <i>Manual of Instructions for the Survey of Public Lands of the United States, 1973</i> . Prepared by the Bureau of Land Management, Technical Bulletin 6.	241
Appendix 2	<i>Classification, Standards of Accuracy, and General Specifications of Geodetic Control Surveys</i> . NOS/NOAA, February, 1974.	259
Appendix 3	<i>Specifications to Support Classification, Standards of Accuracy, and General Specifications of Geodetic Control Surveys</i> . NOS/NOAA, July, 1975.	275
Additional Reading		317
Index		319

ILLUSTRATIONS

- 2.1-1 Statistical Error Distribution and Gaussian Law of Errors 8
- 2.2-1 Locations of the Probable (m), Average (t), Standard (σ), and Maximum Errors 10
- 2.3-1 Triangle 11
- 3.1-1 The Cross Staff Head 15
- 3.1-2 Ray Path in Pentagonal Prism 15
- 3.1-3 Simple Pentagonal Prism 16
- 3.1-4 Double Prism 16
- 3.1-5 Metal Plumbing Rod 17
- 3.1-6 Range Poles 18
- 3.1-7 Setting Out of Straight Lines and Right Angles 19
- 3.1-8 Rod Measurements 21
- 3.1-9 Simple Surveys: Distance Method 22
- 3.1-10 Simple Surveys: Boundary Method 23
- 3.1-11 Simple Surveys: Orthogonal Method 23
- 3.1-12 Sketch of Planimetric Survey 24
- 3.1-13 Optical-Wave Electronic Distance Measuring Instruments 28
- 3.1-14 Microwave Electronic Distance Measuring Instruments 30
- 3.1-15 Area Computation for the Radial Method 31
- 3.1-16 Double Meridian Distance Method 32
- 3.1-17 Graphical Area Determination: Reduction to Triangle of Equal Area 33
- 3.1-18 Graphical Area Determination: Planimetric Templet 33
- 3.1-19 Graphical Area Determinations: Polar Planimeter 34
- 3.1-20 Coordinate Transformation 36
- 3.1-21 Line Intersection 38
- 3.1-22 Approximate Partitioning of Areas 39
- 3.1-23 Control Net 40
- 3.1-24 Schematic Representation of a Simple Theodolite 41
- 3.1-25 Ray Path in a Simple Astronomic Telescope 42
- 3.1-26 Internal Focusing Telescope 43

3.1-27	Level Tube	44
3.1-28	Kern DKM2-A Theodolite	47
3.1-29	Wild Theodolites	48
3.1-30	Simple Angle Measurement	50
3.1-31	Direction Measurement	51
3.1-32	Eccentric Angle Measurement	52
3.1-33	Vertical Angle Measurement	53
3.1-34	The Subtense Bar Method	54
3.1-35	The Stadia Method	55
3.1-36	Wild RDS Self-Reducing Tacheometer	56
3.1-37	Hewlett-Packard EDM Instruments	58
3.1-38	Kern DM 501 Electro-optical Distance Meter	59
3.1-39	Wild DI 3S Distomat	60
3.1-40	Plane Coordinate Computation	61
3.1-41	Intersection	61
3.1-42	Resection	63
3.1-43	Double Point Determination	64
3.1-44	Open Traverse Without Tie to Coordinate System	64
3.1-45	Traverse with Bilateral Tie	65
3.1-46	MOM Gi-B1 Gyroscopic Theodolite	67
3.1-47	Wild GAK 1 Gyro Attachment	68
3.1-48	Radial Survey	69
3.2-1	Scheme of the Spirit Level Instrument	70
3.2-2	Coincidence of the Bubble	71
3.2-3	Wild NK 2 Spirit Level	72
3.2-4	Kern GKO-A Automatic Level	72
3.2-5	Wild Automatic Levels	74, 75
3.2-6	Wild Leveling Staffs	76
3.2-7	Geometric Leveling	77
3.2-8	Trigonometric Leveling	79
3.2-9	Thommen Barometer	83
3.3-1	Traversing with Compass or Gyro Theodolites	87
3.3-2	Kern RK Reducing Alidade	88
3.4-1	Schematic Representation of a Rectifier	91
3.4-2	Wild E4 Rectifier	92
3.4-3	Mirror Stereoscope and Parallax Bar	93
3.4-4	The Principle of Stereophotogrammetry	94
3.4-5	Zeiss PSK Stereocomparator	95
3.4-6	Wild B8S Stereoplotter	96
3.4-7	Wild P31 Universal Terrestrial Camera	97
3.4-8	Wild RC10 Aerial Camera	98
3.4-9	Bausch & Lomb Multiplex	99
3.4-10	Mann Monocomparator	100
3.4-11	Scheme of the OMI Nistri APC-3 Analytical System	101

- 3.5-1 Setting Out a Curve 102
- 4.1-1 First- and Second-Order Control Survey Net 105
- 4.1-2 Geoid and Terrestrial Ellipsoid 106
- 4.1-3 The Reference Ellipsoids 106
- 4.1-4 The Geoid Over the North American Best-Fitting Reference Ellipsoid 107
- 4.1-5 Astronomic and Geodetic Coordinates and the Deflection of the Vertical 108
- 4.1-6 Horizontal Control Network in the U.S. 109
- 4.1-7 Triangulation Tower 110
- 4.1-8 Angle Measurement in All Combinations 111
- 4.1-9 Angle Measurement by Sectors 112
- 4.1-10 Conditions in a Network 113
- 4.1-11 Orthogonal Spherical (Soldner) Coordinates 119
- 4.1-12 Principal Problems in Coordinate Computations 120
- 4.1-13 Coordinates on the Ellipsoid 123
- 4.2-1 The Celestial Sphere 128
- 4.2-2 The Celestial Sphere with the Ecliptic 129
- 4.2-3 The Horizon System 130
- 4.2-4 The Hour Angle System 131
- 4.2-5 The Right Ascension System 132
- 4.2-6 The Ecliptic System 133
- 4.2-7 Relations Between the Horizon and Hour Angle Systems 133
- 4.2-8 The Astronomic Triangle 134
- 4.2-9 Relations Between Hour Angle and Right Ascension Systems 135
- 4.2-10 Astronomical Attachments to the Wild T2 Theodolite 140
- 4.2-11 Wild T3 Precision Theodolite with Astrolabe Attachment 141
- 4.2-12 Zeiss Ni 2 Automatic Level with Astrolabe Attachment 142
- 4.2-13 Simple Radio-Chronograph-Chronometer Set Up 142
- 4.2-14 The Omega Time Recorder 143
- 4.2-15 Universal Theodolites 144
- 4.3-1 Determination of the Reference Ellipsoid from Two Arc Measurements 146
- 4.3-2 Meridian Arc Measurement 146
- 4.3-3 Early Arc Measurements 147
- 4.3-4 Major Geodetic Datums 149
- 4.3-5 Astro-Geodetic Determination of the Geoid 149
- 4.3-6 Equipotential (Level) Surfaces in the Earth's Gravity Field 152
- 4.3-7 Gravimeters 155
- 4.3-8 Integration Over a Sphere 158
- 4.3-9 Location of $1^\circ \times 1^\circ$ Mean Gravity Anomalies 159
- 4.3-10 The GEM 8 Geoid 160
- 4.3-11 The Effect of the Convergence of the Level Surfaces on Geometric Leveling 161

4.4-1	Keplerian Orbital Elements	166
4.4-2	Laser Satellite Tracking Equipment	168
4.4-3	Doppler-Integrator Satellite Tracking Equipment	169
4.4-4	Satellite Tracking Cameras	170, 171
4.4-5	The 45 Stations of the Worldwide BC4 Photogrammetric Satellite Triangulation Network	173
4.4-6	Height Differences After a 7-Parameter Transformation	178
4.4-7	Height Differences After a 3-Parameter Transformation	178
4.4-8	Laser Geodynamic Satellite (LAGEOS)	179
4.4-9	The Shape of the Mean Sea Level	182
4.4-10	Navstar Global Positioning System (GPS)	183
4.4-11	Laser Retroreflector Assembly on the Moon	184
4.4-12	Schematic Cross-Section of the Lunar Laser Observatory on Haleakala, Maui	185
4.4-13	The Fallerscope	185
4.4-14	Basic Geometry of Radio Source Interferometry	186
4.4-15	VLBI Geometry on the Rotating Earth	187
4.4-16	The Transportable End of a VLBI Baseline	188
4.4-17	Inertial Survey System	193
5.3-1	Adjustment of an Intersection	198
5.4-1	Adjustment of a Level Net	202
6.1-1	Conic, Cylindric and Azimuthal Projections	205
6.1-2	Tangent and Secant Projections	205
6.1-3	Normal, Transverse and Oblique Projections	206
6.1-4	The Tissot Indicatrix	207
6.1-5	Diagram of the True Conic Projections	211
6.1-6	Mapping Coordinates of the True Conic Projections	211
6.1-7	True Conformal Conic Projection	212
6.1-8	Normal Conformal Cylindric Projection	213
6.1-9	Diagram of the Transverse Cylindric Projections	214
6.1-10	Transverse Mercator Projection	215
6.1-11	Diagram of the Azimuthal Projections	216
6.1-12	Normal, Transverse, and Oblique Azimuthal Projections	217
6.1-13	Polyconic Projection of the Sphere	219
6.2-1	Examples of Projection Grids	222
6.4-1	LANDSAT-3 Observatory	239

TABLES

- 3.1-1** Statistical Data for Some Electronic Distance Measuring Instruments 27
- 4.3-1** Some Ellipsoids in Current Use 148
- 4.3-2** Geodetic Datums 150
- 4.4-1** Datum Transformation Parameters to Satellite System 177
- 6.1-1** Classification of Map Projections 206
- 6.1-2** True Conic Projections 212
- 6.1-3** Normal Cylindric Projections 213
- 6.1-4** Transverse Cylindric Projections 214
- 6.1-5** Oblique Azimuthal Projections 216
- 6.2-1** List of States with Their Respective Projection Grids 221