

Charles D. Ghilani • Paul R. Wolf

ELEMENTARY SURVEYING

An Introduction to Geomatics

14th Edition



Conversion Factors

Length

1 millimeter (mm) = 1000 micrometers (μm)
 1 centimeter (cm) = 10 mm
 1 meter (m) = 100 cm
 1 m = 39.37 inches (in) [U.S. Survey Foot]
 1 kilometer (km) = 1000 m
 1 km = 0.62137 miles
 1 in. = 25.4 mm *exactly* [International Foot]
 1 ft = 304.8 mm *exactly* [International Foot]
 1 mile = 5280 ft
 1 nautical mile = 6076.10 ft = 1852 m
 1 rod = 1 pole = 1 perch = 16.5 ft
 1 Gunter's chain (ch) = 66 ft = 4 rods
 1 mile = 80 ch
 1 vara = about 33 inches in Mexico and
 California and 33-1/3 inches in Texas
 1 fathom = 6 ft

Volume

1 m³ = 35.31 ft³
 1 yd³ = 27 ft³ = 0.7646 m³
 1 litre = 0.264 gal [U.S.]
 1 litre = 0.001³
 1 gal [U.S.] = 3.785 litres
 1 ft³ = 7.481 gal [U.S.]
 1 gal [Imperial] = 4.546 litres = 1.201 gal [U.S.]

Area

1 mm² = 0.00155 in.²
 1 m² = 10.76 ft²
 1 km² = 247.1 acres
 1 hectare (ha) = 2.471 acres
 1 acre = 43,560 ft²
 1 acre = 10 ch², i.e., 10 (66 ft × 66 ft)
 1 acre = 4046.9 m²
 1 ft² = 0.09290 m²
 1 ft² = 144 in.²
 1 in.² = 6.452 cm²
 1 mile² = 640 acres (normal section)

Angles

1 revolution = 360 degrees = 2π radians
 1° (degree) = 60' (minutes)
 1' = 60" (seconds)
 1° = 0.017453292 radians
 1 radian = 57.29577951° = 57°17'44.806"
 1 radian = 206,264.8062"
 1 revolution = 400 grads (also called gons)
 tan 1" = sin 1" = 0.000004848
 π = 3.141592654

Other Conversions

1 gram (g) = 0.035 oz
 1 kilogram (kg) = 1000 g = 2.20 lb
 1 ton = 2000 lb = 2 kips = 907 kg
 1 m/sec = 3.28 ft/sec
 1 km/hr = 0.911 ft/sec = 0.621 mi/hr

GPS SIGNAL FREQUENCIES

Code	Frequency (MHz)
C/A	1.023
P	10.23
L1	1575.42
L2	1227.60
L5	1176.45

ELLIPSOID PARAMETERS

Ellipsoid	Semimajor Axis (a)	Semiminor Axis (b)	Flattening (1/f)
Clarke, 1866	6,378,206.4	6,356,583.8	294.97870
GRS80	6,378,137.000	6,356,752.314	298.257222101
WGS84	6,378,137.000	6,356,752.314	298.257223563

Some Other Important Numbers in Surveying (Geomatics)

Errors and Error Analysis

68.3 = percent of observations that are expected within the limits of one standard deviation
0.6745 = coefficient of standard deviation for 50% error (*probable error*)
1.6449 = coefficient of standard deviation for 90% error
1.9599 = coefficient of standard deviation for 95% error (*two-sigma error*)

Electronic Distance Measurement

299,792,458 m/sec = speed of light or electromagnetic energy in a vacuum
1 Hertz (Hz) = 1 cycle per second
1 kilohertz (kHz) = 1000 Hz
1 megahertz (MHz) = 1000 kHz
1 gigahertz (GHz) = 1000 MHz
1.0003 = approximate index of atmospheric refraction (varies from 1.0001 to 1.0005)
760 mm of mercury = standard atmospheric pressure

Taping

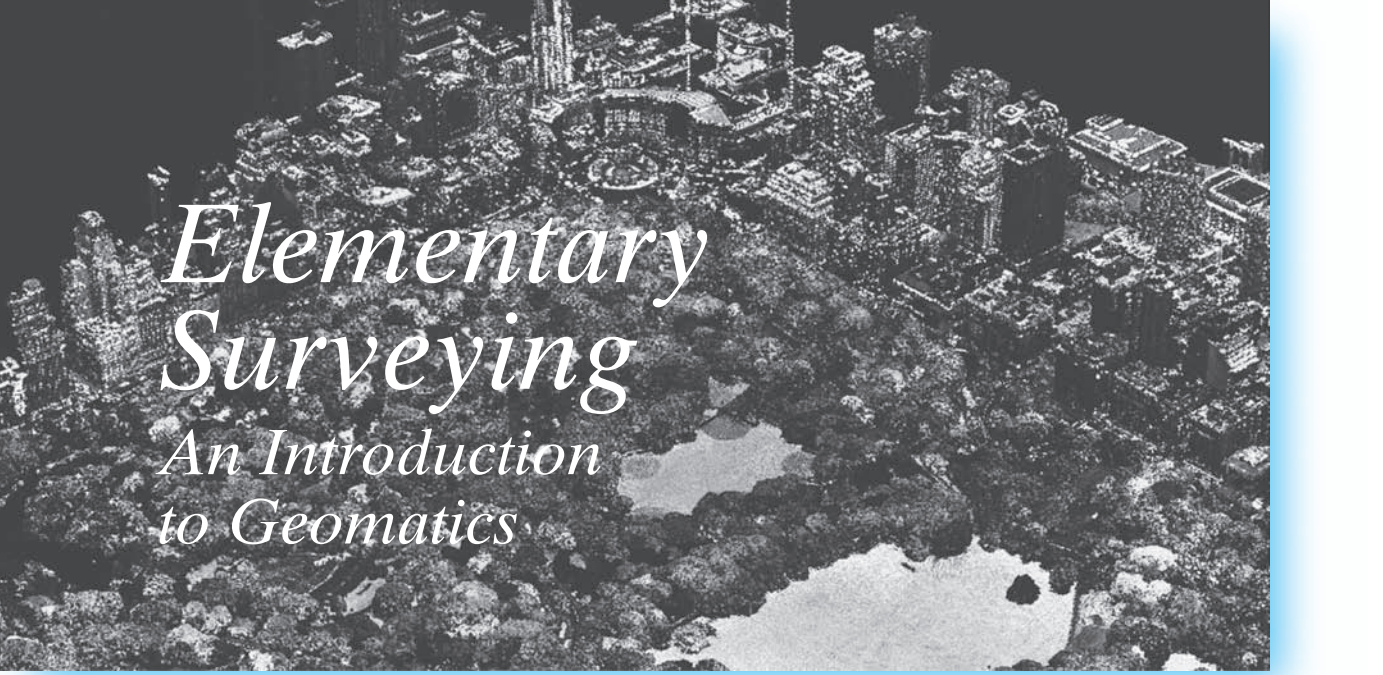
0.00000645 = coefficient of expansion of steel tape, per 1°F
0.0000116 = coefficient of expansion of steel tape, per 1°C
29,000,000 lb/in.² = 2,000,000 kg/cm² = Young's modulus of elasticity for steel
490 lb/ft³ = density of steel for tape weight computations
15°F = change in temperature to produce a 0.01 ft length change in a 100 ft steel tape
68°F = 20°C = standard temperature for taping

Leveling

0.574 = coefficient of combined curvature and refraction (ft/miles²)
0.0675 = coefficient of combined curvature and refraction (m/km²)
20.6 m = 68 ft = approximate radius of a level vial having a 20" sensitivity

Miscellaneous

6,371,000 m = 20,902,000 ft = approximate mean radius of the earth
1.15 miles = approximately 1 minute of latitude = approximately 1 nautical mile
69.1 miles = approximately 1 degree of latitude
101 ft = approximately 1 second of latitude
24 hours = 360° of longitude
15° longitude = width of one time zone, i.e., 360°/24 hr
23°26.5' = approximate maximum declination of the sun at the solstices
23^h56^m04.091^s = length of sidereal day in mean solar time, which is 3m55.909^s of mean solar time short of one solar day
5,729,578 ft = radius of 1° curve, arc definition
5,729,651 ft = radius of 1° curve, chord definition
100 ft = 1 station, English system
1000 m = 1 station, metric system
6 miles = length and width of a normal township
36 = number of sections in a normal township
10,000 km = distance from equator to pole and original basis for the length of the meter



*Elementary
Surveying
An Introduction
to Geomatics*

Fourteenth Edition

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An aerial photograph of a city, likely New York City, showing a dense urban landscape with numerous skyscrapers and buildings. In the center, there is a large, lush green park with a winding path and a body of water. The word "Preface" is written in a white, serif font across the middle of the image.

Preface

This 14th Edition of *Elementary Surveying: An Introduction to Geomatics* is a readable text that presents basic concepts and practical material in each of the areas fundamental to modern surveying (geomatics) practice. It is written primarily for students beginning their study of surveying (geomatics) at the college level. Although the book is introductory to the practice of surveying, its depth and breadth also make it ideal for self-study and preparation for licensing examinations. This edition includes more than 400 figures and illustrations to help clarify discussions, and numerous example problems are worked to illustrate computational procedures. Recognizing the proliferation of intelligent phones and the intention of Internet browsing ability in these phones and tablet devices, QR Codes have been introduced with this edition. These codes indicate that a video lesson on the material is available from the companion website for this book at <http://www.pearsonhighered.com/ghilani> and are accessible using a smart phone or other device with a QR code reader. See sample QR Code to the right. The 65 videos provide complete, step-by-step solution walkthroughs of representative problems from the text and proper instrumentation procedures to use when in the field. These videos also provide additional assistance for students when working with equipment during homework and field exercises or in preparing for an exam or quiz. *Please note: Users must download a QR code reader to their smartphone or tablet. Data and roaming charges may also apply.*



In keeping with the goal of providing an up-to-date presentation of surveying equipment and procedures, total stations are stressed as the instruments for making angle and distance observations. With this in mind, a section on planning a ground-based laser scanning survey has been introduced in this edition. Additionally, the LandXML format to exchange mapping files has also been introduced.

Since taping is now limited to distances under one-tape length and since tape corrections are seldom, if ever, performed in practice, tape correction problems

have been moved to Appendix A. However, it is still important that the study of surveying including a complete presentation of taping so that students understand the proper use of tapes. Thus a discussion of the correction for systematic errors found in taping are still retained in this edition. Furthermore, transits and theodolites, which are not used in practice, are just briefly introduced in the main body of the text for historical purposes. For those who still use these instruments, the reader should refer to previous editions of this book.

As with past editions, this book continues to emphasize the theory of errors in surveying work. At the end of each chapter, common errors and mistakes related to the topic covered are listed so that students will be reminded to exercise caution in all of their work. Practical suggestions resulting from the authors' many years of experience are interjected throughout the text. Many of the 1000 after-chapter problems have been rewritten so that instructors can create new assignments for their students. An Instructor's Manual is available on the companion website at <http://www.pearsonhighered.com/ghilani> for this book to instructors who adopt the book by contacting their Prentice Hall sales representative. Also available on this website are the short videos presenting the solution of selected example problems in this book.

Updated versions of STATS, WOLFPACK, and MATRIX are available on the companion website for this book at <http://www.pearsonhighered.com/ghilani>. These programs contain options for statistical computations, traverse computations for polygon, link, and radial traverses; area calculations; astronomical azimuth reduction; two-dimensional coordinate transformations; horizontal and vertical curve computations; and least-squares adjustments. Mathcad® worksheets and Excel® spreadsheets are included on the companion website for this book. These programmed computational sheets demonstrate the solution to many of the example problems discussed herein. For those desiring additional knowledge in map projections, the Mercator, Albers Equal Area, Oblique Stereographic, and Oblique Mercator map projections have been included with these files. Additionally, instructional videos are available on the companion website demonstrating the solutions of selected problems throughout this book.

WHAT'S NEW

- Video lessons on proper usage of instruments presented in this book.
- Images of new instruments and field book pages that match today's instruments.
- Increased discussions on the changes in reference systems.
- Discussion on planning a laser-scanning survey.
- Discussion on the LandXML drawing exchange format.
- Revised discussion on point codes in field-to-finish surveying.
- Extended coverage on errors present in electronic distance measurements.
- Introduction to mobile mapping systems.
- Revised problem sets.
- Seven new instructional videos, demonstrating instrumental procedures and record keeping.

ACKNOWLEDGMENTS

Previous editions of this book, and this current one, have benefited from the suggestions, reviews, and other input from numerous students, educators, and practitioners. For their help, the authors are extremely grateful. In this edition, those professors and graduate students who reviewed material or otherwise assisted include Robert Schultz, Oregon State University; Steven Frank, New Mexico State University; Jeremy Deal, University of Texas-Arlington; Eric Fuller, St. Cloud State University; Loren J. Gibson, Florida Atlantic University; John J. Rose, Phoenix College; Robert Moynihan, University of New Hampshire; Marlee Walton, Iowa State University; Douglas E. Smith, Montana State University; Jean M. Rüeger, The University of New South Wales, Sydney, Australia; Thomas Seybert, The Pennsylvania State University; Paul Dukas, University of Florida; and Bon DeWitt, University of Florida. The authors would like to acknowledge the following professionals for their contributions and suggestions, including Charles Harpster, Pennsylvania Department of Transportation; Preston Hartzell, University of Houston; Eduardo Fernandez-Falcon, Topcon Positioning Systems; Joseph Gabor; and Brian Naberezny.

In addition, the authors wish to acknowledge the contributions of charts, maps, or other information from the National Geodetic Survey, the U.S. Geological Survey, and the U.S. Bureau of Land Management. Also, appreciation is expressed to the many instrument manufacturers who provided pictures and other descriptive information on their equipment for use herein. To all of those named above, and to any others who may have been inadvertently omitted, the authors are extremely thankful.

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An aerial photograph of a city, likely New York City, showing a dense urban landscape with numerous skyscrapers and buildings. In the center, there is a large, green park area with a winding path and a body of water, possibly Central Park. The image is in black and white, with a blue gradient at the bottom.

1

Introduction

■ 1.1 DEFINITION OF SURVEYING

Surveying, which is also interchangeably called *geomatics* (see Section 1.2), has traditionally been defined as the science, art, and technology of determining the relative positions of points above, on, or beneath the Earth's surface, or of establishing such points. In a more general sense, however, surveying (geomatics) can be regarded as that discipline that encompasses all methods for measuring and collecting information about the physical Earth and our environment, processing that information, and disseminating a variety of resulting products to a wide range of clients. Surveying has been important since the beginning of civilization. Its earliest applications were in measuring and marking boundaries of property ownership. Throughout the years its importance has steadily increased with the growing demand for a variety of maps and other spatially related types of information, and with the expanding need for establishing accurate line and grade to guide construction operations.

Today, the importance of measuring and monitoring our environment is becoming increasingly critical as our population expands; land values appreciate; our natural resources dwindle; and human activities continue to stress the quality of our land, water, and air. Using modern ground, aerial, and satellite technologies, and computers for data processing, contemporary surveyors are now able to measure and monitor the Earth and its natural resources on literally a global basis. Never before has so much information been available for assessing current conditions, making sound planning decisions, and formulating policy in a host of land-use, resource development, and environmental preservation applications.

Recognizing the increasing breadth and importance of the practice of surveying, the *International Federation of Surveyors* (see Section 1.11) adopted the following definition:

A surveyor is a professional person with the academic qualifications and technical expertise to conduct one, or more, of the following activities;

- to determine, measure and represent the land, three-dimensional objects, point-fields, and trajectories;
- to assemble and interpret land and geographically related information;
- to use that information for the planning and efficient administration of the land, the sea and any structures thereon; and
- to conduct research into the above practices and to develop them.

Detailed Functions

The surveyor's professional tasks may involve one or more of the following activities, which may occur either on, above, or below the surface of the land or the sea and may be carried out in association with other professionals.

1. The determination of the size and shape of the earth and the measurements of all data needed to define the size, position, shape and contour of any part of the earth and monitoring any change therein.
2. The positioning of objects in space and time as well as the positioning and monitoring of physical features, structures and engineering works on, above or below the surface of the earth.
3. The development, testing and calibration of sensors, instruments and systems for the above-mentioned purposes and for other surveying purposes.
4. The acquisition and use of spatial information from close range, aerial and satellite imagery and the automation of these processes.
5. The determination of the position of the boundaries of public or private land, including national and international boundaries, and the registration of those lands with the appropriate authorities.
6. The design, establishment, and administration of geographic information systems (GIS), and the collection, storage, analysis, management, display and dissemination of data.
7. The analysis, interpretation, and integration of spatial objects and phenomena in GIS, including the visualization and communication of such data in maps, models and mobile digital devices.
8. The study of the natural and social environment, the measurement of land and marine resources and the use of such data in the planning of development in urban, rural, and regional areas.
9. The planning, development and redevelopment of property, whether urban or rural and whether land or buildings.
10. The assessment of value and the management of property, whether urban or rural and whether land or buildings.
11. The planning, measurement and management of construction works, including the estimation of costs.

In application of the foregoing activities surveyors take into account the relevant legal, economic, environmental, and social aspects affecting each project.

The breadth and diversity of the practice of surveying (geomatics), as well as its importance in modern civilization, are readily apparent from this definition.

■ 1.2 GEOMATICS

As noted in Section 1.1, “geomatics” is a relatively new term that is now commonly being applied to encompass the areas of practice formerly identified as surveying. The principal reason cited for making the name change is that the manner and scope of practice in surveying have changed dramatically in recent years. This has occurred in part because of recent technological developments that have provided surveyors with new tools for measuring and/or collecting information, for computing, and for displaying and disseminating information. It has also been driven by increasing concerns about the environment locally, regionally, and globally, which have greatly exacerbated efforts in monitoring, managing, and regulating the use of our land, water, air, and other natural resources. These circumstances, and others, have brought about a vast increase in demands for new spatially related information.

Historically surveyors made their measurements using ground-based methods, with the transit and tape¹ as their primary instruments. Computations, analyses, and the reports, plats, and maps they delivered to their clients were prepared (in hard-copy form) through tedious manual processes. Today’s surveyor has an arsenal of tools for measuring and collecting environmental information that includes electronic instruments for automatically measuring distances and angles, satellite surveying systems for quickly obtaining precise positions of widely spaced points, and modern aerial digital imaging and laser-scanning systems for quickly mapping and collecting other forms of data about the Earth. In addition, computer systems are available that can process the measured data and automatically produce plats, maps, and other products at speeds unheard of a few years ago. Furthermore, these products can be prepared in electronic formats and be transmitted to remote locations via telecommunication systems.

Concurrent with the development of these new data collection and processing technologies, *geographic information systems* (GISs) have emerged and matured. These computer-based systems enable virtually any type of spatially related information about the environment to be integrated, analyzed, displayed, and disseminated.² The key to successfully operating GISs is spatially related data of high quality, and the collection and processing of this data is placing great new demands upon the surveying community.

As a result of these new developments noted above, and others, many feel that the name surveying no longer adequately reflects the expanded and changing role of their profession. Hence the new term “geomatics” has emerged. In this text, the terms “surveying” and “geomatics” are both used, although the

¹These instruments are described in Appendix A and Chapter 6, respectively.

²Geographic information systems are briefly introduced in Section 1.9 and then described in greater detail in Chapter 28.

former is used more frequently. Nevertheless students should understand that the two terms are synonymous as discussed above.

■ 1.3 HISTORY OF SURVEYING

The oldest historical records in existence today that bear directly on the subject of surveying state that this science began in Egypt. Herodotus recorded that Sesostris (about 1400 B.C.) divided the land of Egypt into plots for the purpose of taxation. Annual floods of the Nile River swept away portions of these plots, and surveyors were appointed to replace the boundaries. These early surveyors were called *rope-stretchers*, since their measurements were made with ropes having markers at unit distances.

As a consequence of this work, early Greek thinkers developed the science of geometry. Their advance, however, was chiefly along the lines of pure science. Heron stands out prominently for applying science to surveying in about 120 B.C. He was the author of several important treatises of interest to surveyors, including *The Dioptra*, which related the methods of surveying a field, drawing a plan, and making related calculations. It also described one of the first pieces of surveying equipment recorded, the *dioptra* [Figure 1.1(a)]. For many years Heron's work was the most authoritative among Greek and Egyptian surveyors.

Significant development in the art of surveying came from the practical-minded Romans, whose best-known writing on surveying was by Frontinus. Although the original manuscript disappeared, copied portions of his work have been preserved. This noted Roman engineer and surveyor, who lived in the first century, was a pioneer in the field, and his essay remained the standard for many years. The engineering ability of the Romans was demonstrated by their extensive construction work throughout the empire. Surveying necessary for this construction resulted in the organization of a surveyors' guild. Ingenious instruments

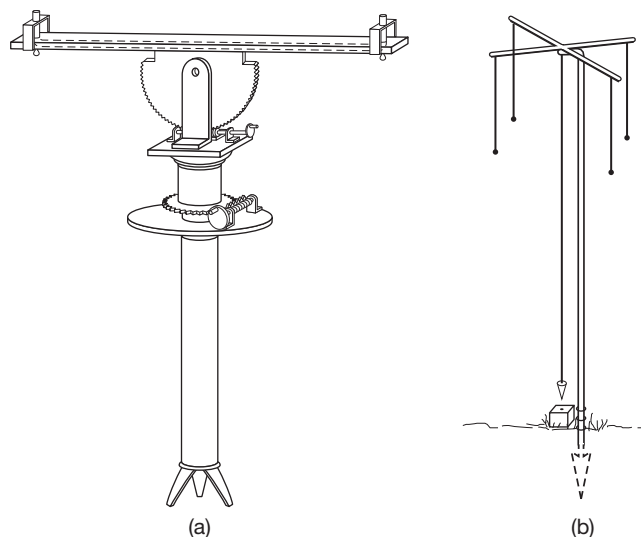


Figure 1.1
Historical surveying instruments: (a) the dioptra and (b) the groma.

were developed and used. Among these were the *groma* [Figure 1.1(b)], used for sighting; the *libella*, an A-frame with a plumb bob, for leveling; and the *chorobates*, a horizontal straightedge about 20 ft long with supporting legs and a groove on top for water to serve as a level.

One of the oldest Latin manuscripts in existence is the *Codex Acerianus*, written in about the 6th century. It contains an account of surveying as practiced by the Romans and includes several pages from Frontinus's treatise. The manuscript was found in the 10th century by Gerbert and served as the basis for his text on geometry, which was largely devoted to surveying.

During the Middle Ages, the Arabs kept Greek and Roman science alive. Little progress was made in the art of surveying, and the only writings pertaining to it were called "practical geometry."

In the 13th century, Von Piso wrote *Practica Geometria*, which contained instructions on surveying. He also authored *Liber Quadratorum*, dealing chiefly with the *quadrans*, a square brass frame having a 90° angle and other graduated scales. A movable pointer was used for sighting. Other instruments of the period were the *astrolabe*, a metal circle with a pointer hinged at its center and held by a ring at the top, and the *cross staff*, a wooden rod about 4 ft long with an adjustable crossarm at right angles to it. The known lengths of the arms of the cross staff permitted distances to be measured by proportion and angles.

Early civilizations assumed the Earth to be a flat surface, but by noting the Earth's circular shadow on the moon during lunar eclipses and watching ships gradually disappear as they sailed toward the horizon, it was slowly deduced that the planet actually curved in all directions.

Determining the true size and shape of the Earth has intrigued humans for centuries. History records that a Greek named Eratosthenes was among the first to compute its dimensions. His procedure, which occurred about 200 B.C., is illustrated in Figure 1.2. Eratosthenes had concluded that the Egyptian cities of Alexandria and Syene were located approximately on the same meridian, and

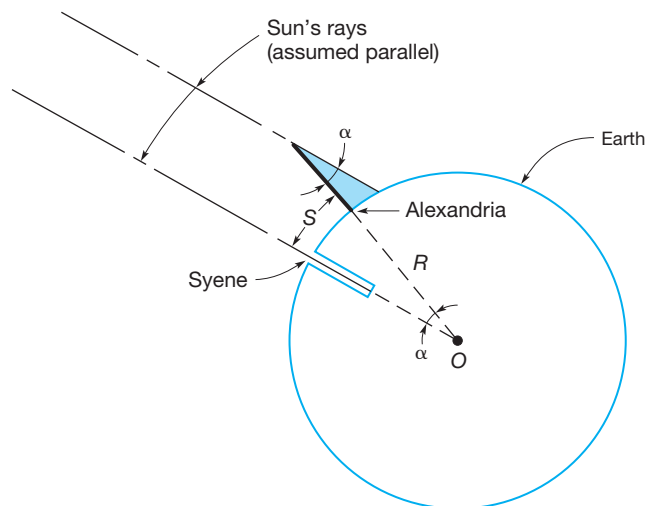


Figure 1.2
Geometry of the procedure used by Eratosthenes to determine the Earth's circumference.

he had also observed that at noon on the summer solstice, the sun was directly overhead at Syene. (This was apparent because at that time of that day, the image of the sun could be seen reflecting from the bottom of a deep vertical well there.) He reasoned that at that moment, the sun, Syene, and Alexandria were in a common meridian plane, and if he could measure the arc length between the two cities, and the angle it subtended at the Earth's center, he could compute the Earth's circumference. He determined the angle by measuring the length of the shadow cast at Alexandria from a vertical staff of known length. The arc length was found from multiplying the number of caravan days between Syene and Alexandria by the average daily distance traveled. From these measurements, Eratosthenes calculated the Earth's circumference to be about 25,000 mi. Subsequent precise geodetic measurements using better instruments, but techniques geometrically similar to Eratosthenes', have shown his value, though slightly too large, to be amazingly close to the currently accepted one. (Actually, as explained in Chapter 19, the Earth approximates an oblate spheroid having an equatorial radius about 13.5 mi longer than the polar radius.)

In the 18th and 19th centuries, the art of surveying advanced more rapidly. The need for maps and locations of national boundaries caused England and France to make extensive surveys requiring accurate triangulation; thus, geodetic surveying began. The U.S. Coast Survey (now the National Geodetic Survey of the U.S. Department of Commerce) was established by an act of Congress in 1807. Initially its charge was to perform hydrographic surveys and prepare nautical charts. Later its activities were expanded to include establishment of reference monuments of precisely known positions throughout the country.

Increased land values and the importance of precise boundaries, along with the demand for public improvements in the canal, railroad, and turnpike eras, brought surveying into a prominent position. More recently, the large volume of general construction, numerous land subdivisions that require precise records, and demands posed by the fields of exploration and ecology have entailed an augmented surveying program. Surveying is still the sign of progress in the development, use, and preservation of the Earth's resources.

In addition to meeting a host of growing civilian needs, surveying has always played an important role in our nation's defense activities. World Wars I and II, the Korean and Vietnam conflicts, and the more recent conflicts in the Middle East and Europe have created staggering demands for precise measurements and accurate maps. These military operations also provided the stimulus for improving instruments and methods to meet these needs. Surveying also contributed to, and benefited from, the space program where new equipment and systems were needed to provide precise control for missile alignment, and for mapping and charting portions of the moon and nearby planets.

Developments in surveying and mapping equipment have now evolved to the point where the traditional instruments that were used until about the 1960s or 1970s—the transit, theodolite, dumpy level, and steel tape—have now been almost completely replaced by an array of new “high-tech” instruments. These include electronic *total station instruments*, which can be used to automatically measure and record horizontal and vertical distances, and horizontal and vertical angles; and *Global Navigation Satellite Systems* (GNSS)



Figure 1.3
LEICA TPS 1100
total station
instrument.
(Courtesy Leica
Geosystems AG.)



Figure 1.4
The IP-S2 3D
mobile mapping
system. (Courtesy
Topcon Positioning
Systems.)

such as the *Global Positioning Systems* (GPS) that can provide precise location information for virtually any type of survey. Laser-scanning instruments combine automatic distance and angle measurements to compute dense grids of coordinated points. Also new aerial cameras and remote sensing instruments have been developed, which provide images in digital form, and these images can be processed to obtain spatial information and maps using new *digital photogrammetric restitution instruments* (also called *softcopy plotters*). Figures 1.3, 1.4, 1.5, and 1.6, respectively, show a total station instrument, 3D mobile mapping system, laser-scanning instrument, and modern softcopy plotter. The 3D mobile mapping system in Figure 1.4 is an integrated system consisting of scanners, GNSS receiver, inertial measurement unit, and a high-quality hemispherical digital camera that can map all items within 100 m of the vehicle as the vehicle travels at highway speeds. The system can capture

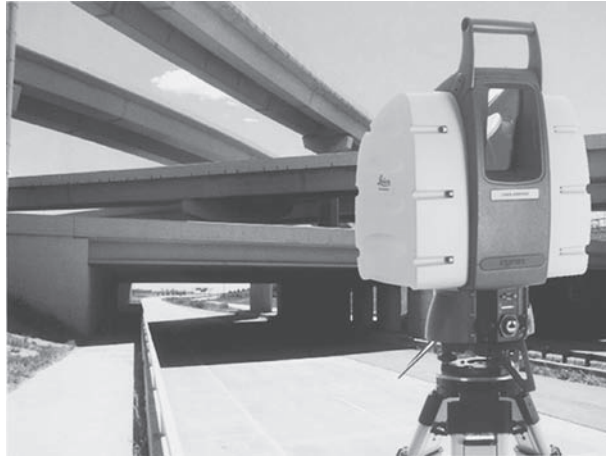


Figure 1.5
LEICA HDS 3000
D24 laser scanner.
(Courtesy of
Christopher
Gibbons, Leica
Geosystems AG.)



Figure 1.6
Intergraph Image
Station Z softcopy
plotter. (Courtesy
of Bon DeWitt.)

1.3 million data points per second providing the end user with high-quality, georeferenced coordinates on all items visible in the images.

■ 1.4 GEODETIC AND PLANE SURVEYS

Two general classifications of surveys are *geodetic* and *plane*. They differ principally in the assumptions on which the computations are based, although field measurements for geodetic surveys are usually performed to a higher order of accuracy than those for plane surveys.

In geodetic surveying, the curved surface of the Earth is considered by performing the computations on an *ellipsoid* (curved surface approximating the size

and shape of the Earth—see Chapter 19). It is now becoming common to do geodetic computations in a 3D, *Earth-Centered, Earth-Fixed* (ECEF) Cartesian coordinate system. The calculations involve solving equations derived from solid geometry and calculus. Geodetic methods are employed to determine relative positions of widely spaced monuments and to compute lengths and directions of the long lines between them. These monuments serve as the basis for referencing other subordinate surveys of lesser extents.

In early geodetic surveys, painstaking efforts were employed to accurately observe angles and distances. The angles were measured using precise ground-based theodolites, and the distances were measured using special tapes made from metal having a low coefficient of thermal expansion. From these basic measurements, the relative positions of the monuments were computed. Later, electronic instruments were used for observing the angles and distances. Although these latter types of instruments are still sometimes used on geodetic surveys, satellite positioning has now almost completely replaced other instruments for these types of surveys. Satellite positioning can provide the needed positions with much greater accuracy, speed, and economy. GNSS receivers enable ground stations to be located precisely by observing distances to satellites operating in known positions along their orbits. GNSS surveys are being used in all forms of surveying including geodetic, hydrographic, construction, and boundary surveying. When combined with a real-time network (RTN), GNSS surveys are capable of providing accuracy within 0.1 ft over a 50-km region with as little as 3 min of data. The principles of operation of GPS are given in Chapter 13, field and office procedures used in static GNSS surveys are discussed in Chapter 14, and the methods used in kinematic GNSS surveys including RTNs are discussed in Chapter 15.

In plane surveying, except for leveling, the reference base for fieldwork and computations is assumed to be a flat horizontal surface. The direction of a plumb line (and thus gravity) is considered parallel throughout the survey region, and all observed angles are presumed to be plane angles. For areas of limited size, the surface of our vast ellipsoid is actually nearly flat. On a line 5 mi long, the ellipsoid arc and chord lengths differ by only about 0.02 ft. A plane surface tangent to the ellipsoid departs only about 0.7 ft at 1 mi from the point of tangency. In a triangle having an area of 75 square miles, the difference between the sum of the three ellipsoidal angles and three plane angles is only about 1 sec. Therefore, it is evident that except in surveys covering extensive areas, the Earth's surface can be approximated as a plane, thus simplifying computations and techniques. In general, algebra, plane and analytical geometry, and plane trigonometry are used in plane-surveying calculations. Even for very large areas, map projections, such as those described in Chapter 20, allow plane-surveying computations to be used. This book concentrates primarily on methods of plane surveying, an approach that satisfies the requirements of most projects.

■ 1.5 IMPORTANCE OF SURVEYING

Surveying is one of the world's oldest and most important arts because, as noted previously, from the earliest times it has been necessary to mark boundaries and divide land. Surveying has now become indispensable to our modern