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LAND SURVEYING METHODS - TERRESTRIAL 3D SCANNERS

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Course #:	SUR-114
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SUR-114 EXAM PREVIEW

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Exam Preview:

1. 3D laser scanners can be used for detailed mapping of large objects such as facilities, structures, utilities, and ground planes.
    a. True
    b. False
2. Laser scanners operate similarly to reflectorless total stations. However, instead of a single shot point being observed, a full field-of-view scan is performed--at a speed upwards of ____ points per second.
    a. 500,000
    b. 400,000
    c. 200,000
    d. 100,000
3. The accuracy of a scanned object can be relative or absolute. In many cases, relative accuracies are far more important than absolute geospatial accuracies.
    a. True
    b. False
4. Laser scanners can be set to any desired scan ___ , e.g., 5 mm to 1 meter, usually based on some short nominal distance. The higher the ___ the larger the resulting dataset--and more time-consuming data editing and processing. The purpose of the project determines the required ____.
    a. Density
    b. Range
    c. Grouping
    d. Focus

5. Field-of-View - Depending on the model and project requirements, scanners can be set to scan a full 360 deg field or zoomed (windowed) into a narrowly set field-of-view.
    a. True
    b. False
6. ____ forces data to be collected from multiple angles for complete data coverage.
    a. Field of view
    b. Side view
    c. Laser point variation
    d. Laser shadowing
7. Overlapping scans allow a full 3D model of a building to be generated using imagery correlation (optical recognition) software (similar to soft-copy photogrammetry). The scanned "___" are saved on flash memory devices in the scanner, which can be later downloaded to a field or office computer. The overlapping "___" from each scan are edited for data spikes--often a lengthy process. They are then merged to form the full 3D model.
    a. point clouds
    b. multiple scans
    c. data processing
    d. geospatial references
8. Most structures require multiple scans in order to develop a complete 3D model. In addition, multiple scans are required to cover hidden, shadowed, or obstructed areas in a single scan.
    a. True
    b. False
9. Once the model is generated, a variety of computer graphic enhancements can be performed. These include coloring, wire meshing, rendering, and smoothing objects.
    a. True
    b. False
10. Final data processing takes about the same time as a scan. A structure that is scanned in 4 hours will typically take about 4 hours to process the data to a CADD compatible format.
    a. True
    b. False

Chapter 10
Terrestrial 3D Laser Scanners

10-1. Purpose

This chapter provides an overview of 3D laser scanners used for detailed mapping of facilities, structures, utilities, and ground planes. High-precision/high-definition tripod mounted laser scanners are covered. Examples of recent applications where these instruments have been used to map Corps facilities or structures are provided.

Figure 10-1. Optech ILRIS 3D laser scanner--detailed mapping of structures and facilities at St. Lucie Lock and Dam, Jacksonville District (Arc Surveying & Mapping, Inc.)

10-2. Background

Laser scanners operate similarly to reflectorless total stations. However, instead of a single shot point being observed, a full field-of-view scan is performed--at a speed upwards of 500,000 points per second. Unlike a total station, the location of the scanner is not usually a required input--resulting in points that are spatially referenced to the instrument and not real-world coordinates. This is somewhat analogous to an uncontrolled photogrammetric model. (Newer models allow input of the scanner coordinates from which all observed pixels may be directly georeferenced). The resultant imagery from a scan (termed a "point cloud") provides a full 3D model of the facility, utility, or terrain that was scanned. Objects can be scanned at a high density--with output pixels smaller than 5 mm. Relative 3D accuracies approaching the millimeter level are claimed, based on redundant observations over a surface. However, 5 to 10 mm accuracy is more realistic in practice. Scans can be rapidly made--a full field-of-view scan of a site or structure can be performed in 5 to 15 minutes per setup (multiple setups generally are required to fully detail a given site or structure). Unlike a total station, however, laser scanners have no means of assigning feature codes or attributes to the measured points--this must be done in post-processing, and is often a tedious and time-consuming process. Laser scanners have increasing application to many Corps civil and military missions. They can be used to perform traditional topographic surveys (detailed planimetry and elevations) of project sites and facilities--providing ground elevations at a high density. These scanners are especially useful in detailed mapping of exposed (and hard to access) utility systems, such as those inside a hydroelectric power plant. They also have application in mapping archeological sites, HTRW sites, dams, rock faces, hazardous traffic areas, unexploded ordinance sites, or any other inaccessible location.

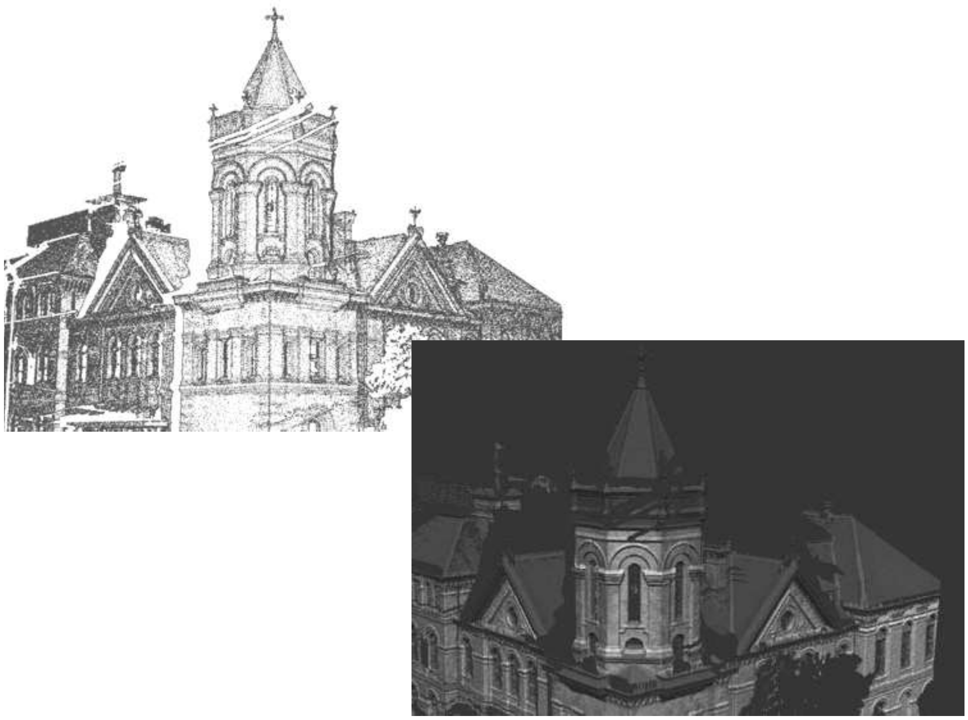

Figure 10-2. Laser scanned image (upper left) and rendered image (lower right) of Corps Mississippi River Division headquarters building, Vicksburg, MS (ARC Surveying & Mapping, Inc.)

a. Manufacturers. Laser scanners have been on the market for only a few years--since the late 1990s. As of 2005, there were about 12 manufacturers of laser scanners listed in trade publications.

b. Cost. A complete laser scanning system (including a high-end modeling software package and training) can cost between $150,000 and $200,000. Thus, few, if any Corps Districts would have a sufficient number of applications to justify this level of expense. In time, it is possible these prices will decrease to a level where 3D scanners may be cost-effective if the workload warrants. Data processing and modeling software is typically expensive; however, it is essential in order to export scanned images to CADD platforms. At present, Corps Districts contract for periodic 3D scanning services--many AE surveying contractors performing Corps work have acquired (or are acquiring) 3D scanners. Given the limited amount of work, the hourly/daily rate is understandably high for these scanners (and data processing)--daily operating costs of $2,000 to $5,000 or more (including processing) are not uncommon, and can vary widely depending on the amount of processing required. Most often, a project cost would be negotiated on a lump sum basis, factoring in the basic daily rental cost of the scanner plus the operator and CADD processor time estimates.

c. Accuracy. The accuracy of a scanned object can be relative or absolute. Relative accuracies are very good (5 mm or better at close ranges). Absolute accuracies depend on the accuracy of the control network developed for the site, how accurately the instrument is aligned to this network, and how well overlapping images (i.e., picture points or targets) are transferred and adjusted (best fit). In general, absolute accuracies can be kept within 1 or 2 centimeters over a small project/structure site. In many cases, relative accuracies are far more important than absolute geospatial accuracies. For example, measurement of a crack in a wall requires a high relative accuracy; however, the absolute geospatial coordinates of the crack are not significant. Overall accuracy is a function of range, scan density, spot/footprint size, and single point accuracy (Jacobs 2004).

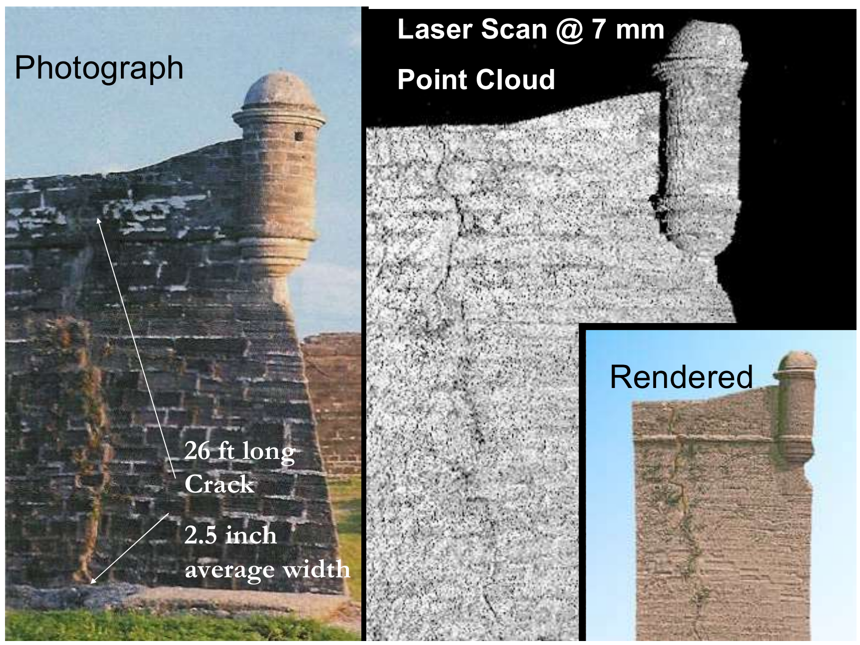

Figure 10-3. Crack measurements with a 3D laser scanner. Castillo de San Marcos, Saint Augustine, FL (Arc Surveying & Mapping, Inc. for National Park Service)

d. Density of scanned points. Laser scanners can be set to any desired scan density, e.g., 5 mm to 1 meter, usually based on some short nominal distance. The higher the density the larger the resulting dataset--and more time-consuming data editing and processing. The purpose of the project determines the required density. For general 3D planimetry or buildings or ground elevations, a low density can be set. For detailed maps of structural members or concrete cracks, a high density is set.

e. Field-of-View. Depending on the model and project requirements, scanners can be set to scan a full 360 deg field or zoomed (windowed) into a narrowly set field-of-view. The Leica HDS4500 scanner has a field-of-view of 360 deg horizontal by 310 deg vertical. The reality of scanning means that even a 360º field of view does not guarantee full area coverage; in fact, it rarely does. Laser shadowing forces data to be collected from multiple angles for complete data coverage. A large field of view does not alleviate this requirement. Also, the angle of incidence of a measurement will have a profound impact on its accuracy and the resolution of the data in general. Keeping this fact in mind, imagine surveying a long, flat wall. If the scanner has a 180º horizontal field of view it will be able to survey the wall in a single scan. Depending on the length of the wall, measurements may be collected from angles that approach 90º, but the reliability of these measurements will be very poor.

f. Range. Range of scans is a function of the laser intensity and reflectivity of the object scanned. Some scanners are designed for only close up scans--i.e. 200 meters. Others claim ranges of upwards of 1,000 meters--or more. Obviously, the longer the range, the larger the footprint and less accurate the resultant measurement becomes. In general, most detailed scans of facilities, buildings, and structures are kept at close range--usually less than 500 ft and not much beyond 1,000 ft. The laser eye safety classification may also be a factor in longer-range scanners--a Class 3 type laser may not be desirable for surveying a populated beach but would be acceptable at a remote HTRW site. (A Class 1 laser device “denotes exempt lasers or laser systems that cannot produce a hazard under normal operating conditions” and a Class 3a laser device “denotes visible lasers or laser systems that normally would not produce a hazard if viewed for only momentary periods with the unaided eye. They may present a hazard if viewed using collecting optics.”). The ranging capability of a laser scanner is more important than it first seems. In some cases, the lack of ranging ability will completely eliminate the ability to do certain projects. For example, let’s examine the case of a bridge that crosses a body of water. A lack of certain characteristics (such as a 360º field of view) may force you to collect more scans but it doesn’t prevent the project from being completed. The inability to range to the structure, with no provisional means of getting closer, will eliminate the potential of the scanner being used on the project. It is also true that a survey will rarely be conducted at a range greater then a few hundred meters (except in cases similar to the above example). However, long-ranging capability has other benefits that are not immediately identifiable. At the extreme limit of a scanners specified range, the accuracy of the measurements will begin to decrease in a non-linear fashion. As such, let’s consider the example of scanning a structure from 150 m away. The scanner whose maximum range is 150-200 m will struggle to collect the data. It may succeed, but the measurement quality will suffer and the dataset will contain a large number of “drop out” points (instances where no measurement was collected). Alternatively, the scanner that provides 1,000 m range will be collecting data from the ideal area of its total dynamic range. The data collected will be of optimum accuracy.

g. Beam footprint size. The footprint size will vary (increase) with the distance from the scanner to the object. Typically, on close-range applications (less than 100 ft ranges), a 5 mm footprint is observed.

10-3. Scanner Operation and Data Processing

Scanners are normally mounted on a tripod, directly onto the plate or in a standard tribrach. The scanner is set up at any arbitrary location that affords the best view of the area or object to be mapped. No absolute geospatial orientation of the scanner is required (unless the scanner model is designed to incorporate geospatial references). Most structures require multiple scans in order to develop a complete 3D model, as illustrated in Figure 10-4 below. In addition, multiple scans are required to cover hidden, shadowed, or obstructed areas in a single scan. Thus, a rectangular building will require scans from four setups offset from each of the corners--each scan providing data covering two faces of the building, which will overlap with adjacent scan locations. These overlapping scans allow a full 3D model of the building to be generated using imagery correlation (optical recognition) software (similar to soft-copy photogrammetry). The scanned “point clouds” are saved on flash memory devices in the scanner, which can be later downloaded to a field or office computer. The overlapping “point clouds” from each scan are edited for data spikes--often a lengthy process. They are then merged to form the full 3D model. This merging is done in proprietary software that is usually sold separately with the laser scanner. This resultant 3D model is referenced only to a relative/internal coordinate system. If real-world geographic X-Y-Z coordinates are required (and they are not always needed for many project applications), then targeted points need to be set in the scanned area/structure in order to perform a standard coordinate transformation. Once the model is generated, a variety of computer graphic enhancements can be performed. These include coloring, wire meshing, rendering, and smoothing objects. Rough point cloud images of solid objects can be smoothed using various software-fitting routines--e.g., items such as wall faces, cylindrical pipes, etc. If the resultant model is going to be exported to a CADD or GIS platform, then additional descriptor, attribute, or layer/level assignments may be required. Final data processing can represent a significant effort on some projects--a structure that is scanned in 4 hours may take as much as 40 hours or longer to process the data to a CADD compatible format. The software used for processing scanned datasets is a critical component in the overall efficiency and economy of the process.

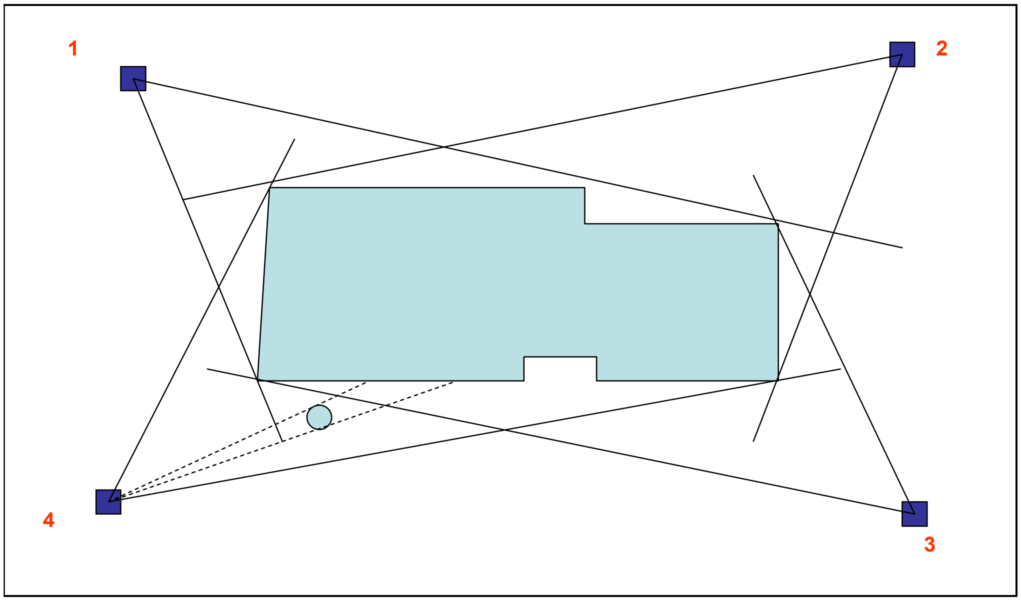

Figure 10-4. Typical four scan locations needed to fully model a building and cover obscured areas. In practice, additional scan points may be needed.

10-4. Corps of Engineers Project Application: St. Lucie Lock and Dam, Jacksonville District

The following figures illustrate an application of 3D laser scanning on a Corps civil works project--mapping lock and dam structures and related grounds and facilities. This project (in 2001) involved both topographic and hydrographic surveying of the lock and dam site. An Optech laser scanner was used to capture images around the project. Given the complexity of the site, numerous instrument setups were required to fully cover the site. The individual point clouds were merged and a continuous 3D model of the lock and dam was created. Additional color rendering was also performed. The above ground Optech laser data set was subsequently merged with 3D hydrographic data obtained with a multibeam echo sounder. (This project was performed by Arc Surveying & Mapping, Inc. for the Jacksonville District).

Figure 10-5. Typical scan location to cover downstream gate structures--instrument set up between 6th and 7th gates

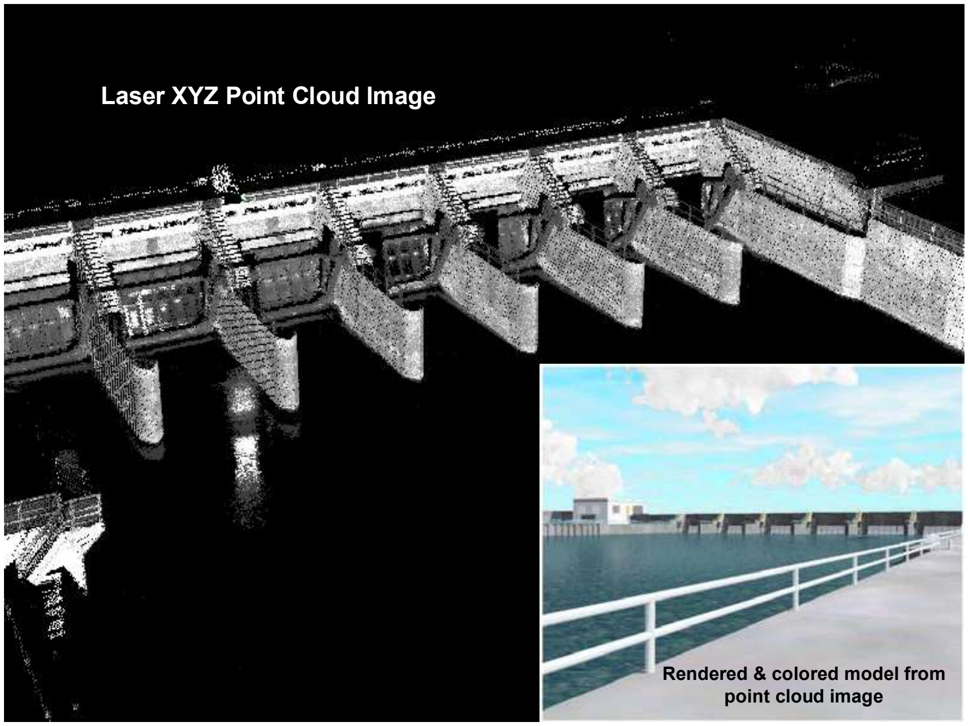

Figure 10-6. Merged point cloud images of gate structures, from multiple scanning locations

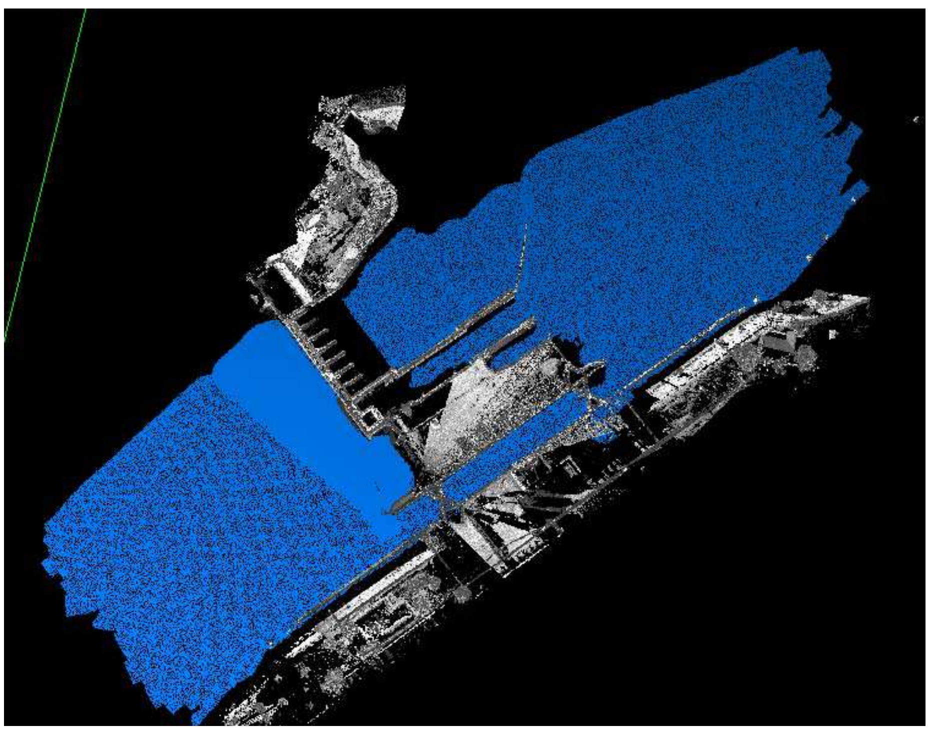

Figure 10-7. Merged Optech laser scanned imagery with subsurface multibeam imagery--resultant 3D imagery model of entire lock and dam project

10-5. Corps of Engineers Project Application: Portuguese Dam Foundation Construction, Ponce, PR, Jacksonville District

The following figures depict a topographic survey of the foundation for the Portuguese Dam north of Ponce, Puerto Rico. These scans were made during grouting operations at the foundation. The entire area surrounding the foundation was scanned, and georeferenced to the local coordinate system using targeted reference points in the scans. A conventional total station survey on a 10 ft x 10 ft grid was performed over the same area and compared with the far denser matrix generated from the laser scan. Rappelling techniques had to be employed to reach many of the total station shot points in this rugged mountainous terrain--these same points were easily and safely tied in with a Cyrax 3D laser scanning system (Cyra Technologies--now Leica). These surveys were performed in 2000 by Arc Surveying & Mapping for the Jacksonville District.

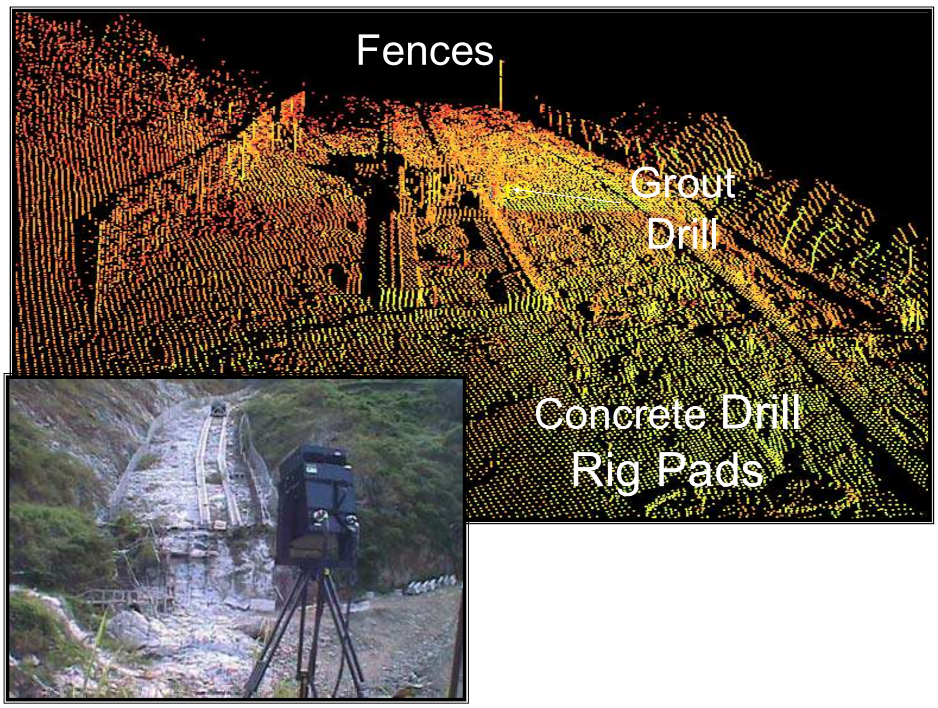

Figure 10-8. Portion of Portuguese Dam foundation scanned by Cyrax laser (Arc Surveying & Mapping, Inc.)

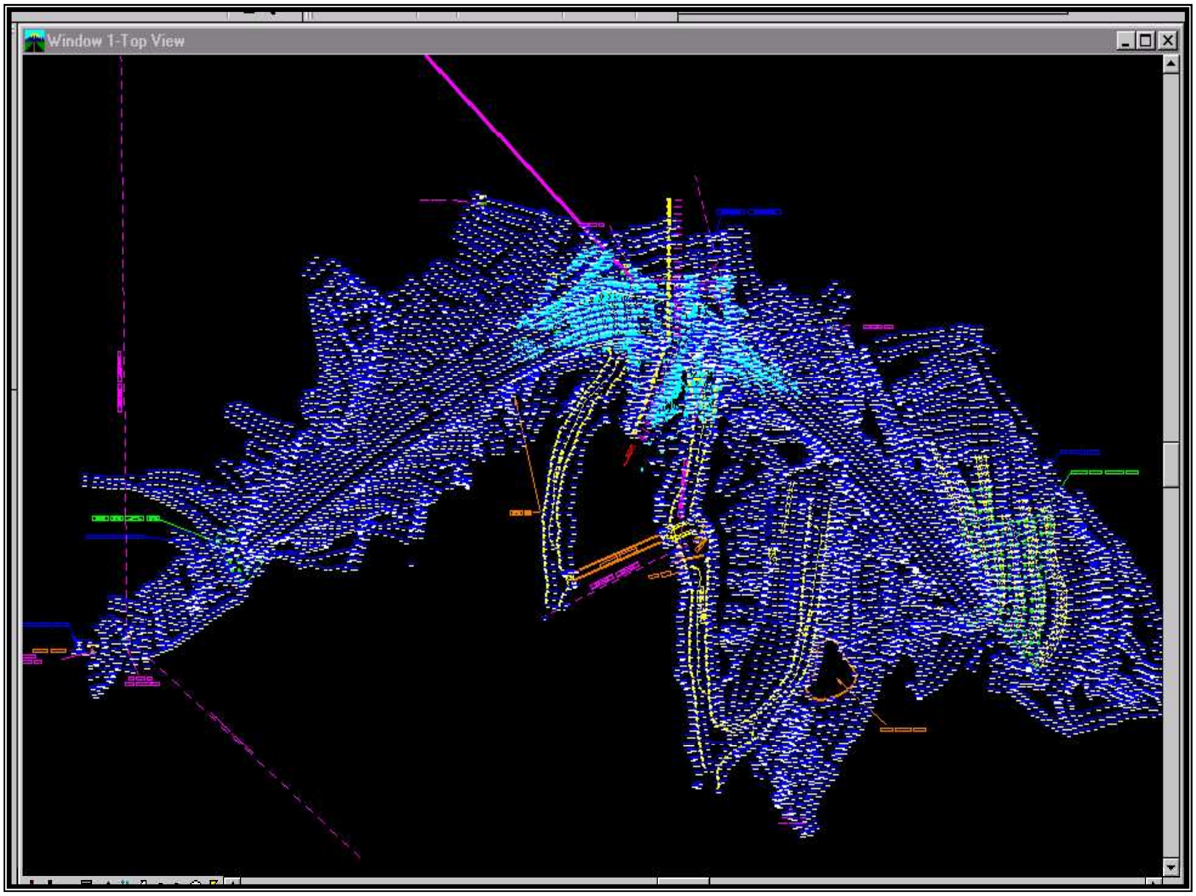

Figure 10-9. Merged datasets: Conventional total station topography and 3D laser scanned model (Portuguese Dam foundation--Jacksonville District)

10-6. Corps of Engineers Application: Steel Bayou Levee Surveys, Vicksburg District

The following figures depict a topographic survey of a levee using a 3D laser scanner. This was a demonstration project performed for the Vicksburg District; to assess the capabilities of terrestrial laser scanners for levee surveys. Comparisons were made between the scanned surveys and conventional topographic surveys performed by the Vicksburg District. A major problem with scanning flat terrain is the limited range when the scanner is set on a standard tripod. To be effective, an elevated platform is needed to obtain a more effective working range. Establishing georeferencing on the scanned images is also problematic in a linear scan over a flat area. Targeted control along the top of the levee is needed to reference each scan and may not be a cost-effective process. In addition, this demonstration project was conducted with 2-ft height grass on the levee. Since the laser picks up the top of grass, any practical use of 3D laser scanners must be performed immediately after vegetation is cleared--or in sites without vegetation. Effective use of laser scanners on flat terrain is marginal unless an elevated view site can be obtained.

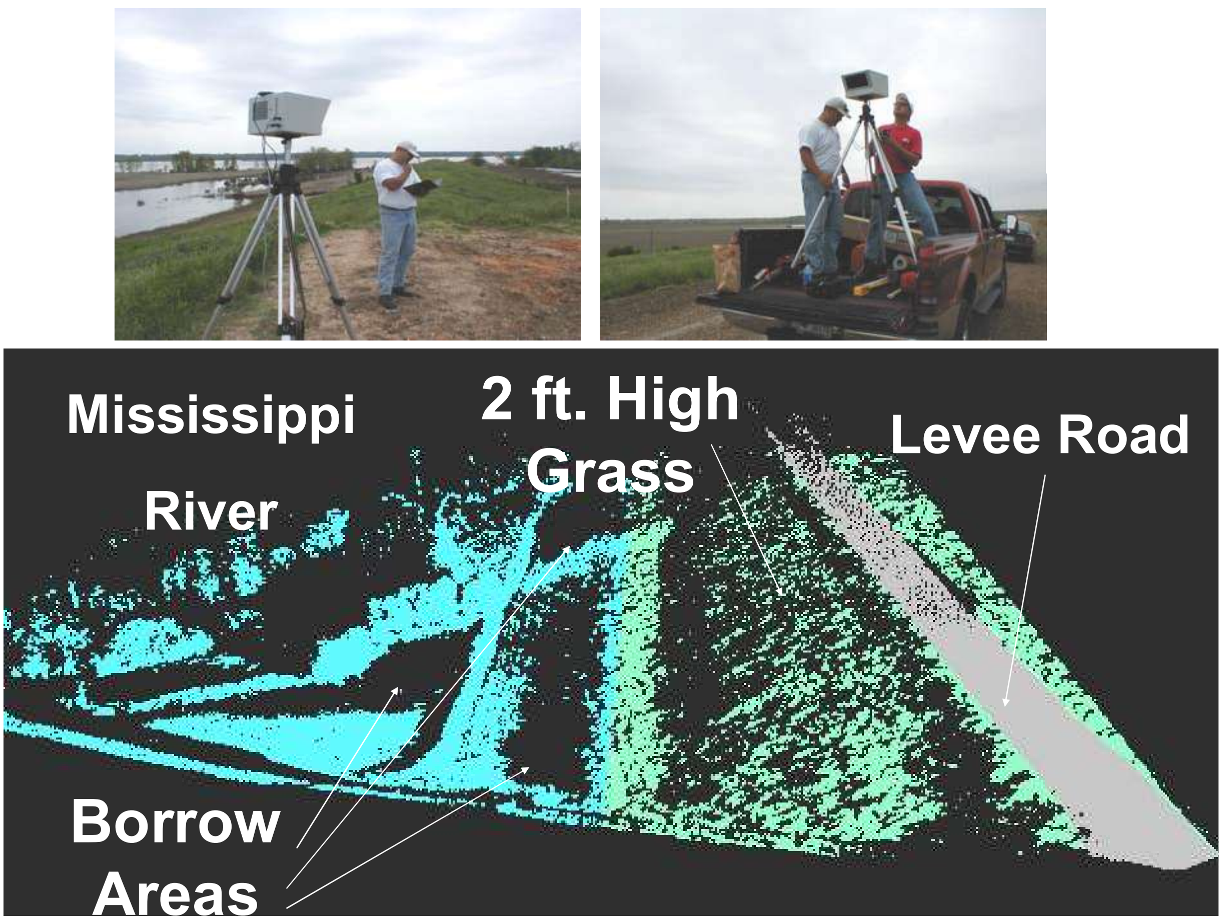

Figure 10-10. Scanned images of Steel Bayou levee in Vicksburg District. Scanner elevated to maximum height in order to extend distance.

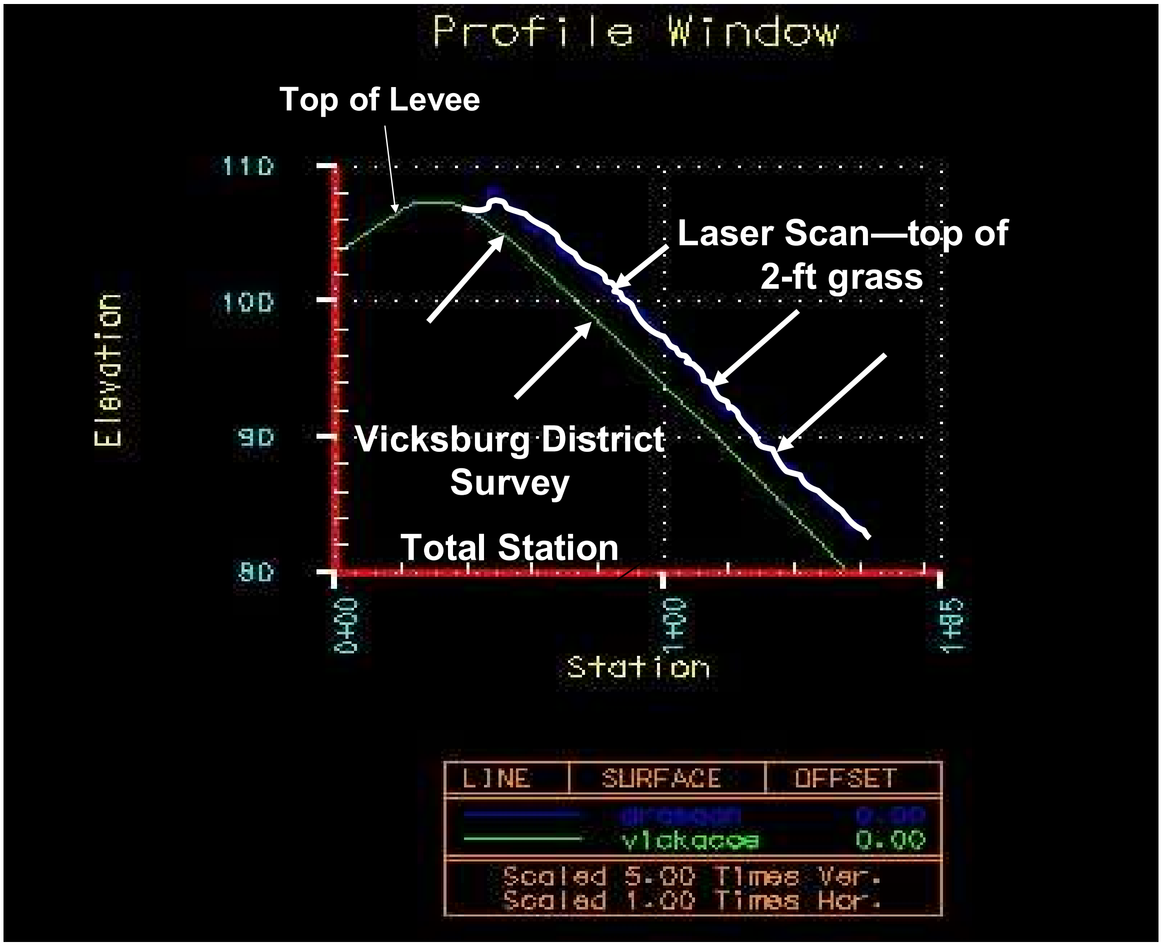

Figure 10-11. Levee cross-section: comparison between conventional total station survey and 3D laser scanner

10-7. Corps of Engineers Application: Structure Subsidence Survey, Philadelphia District

The following figures illustrate another application of 3D laser scanning on a Corps civil works project--monitoring subsidence for lock and dam structures. This was a demonstration project performed by TVGA Consultants for the Philadelphia District, to assess the capabilities of terrestrial scanners for subsidence monitoring. The location of dam outfall structure for the Francis E. Walter Dam makes access extremely difficult, time consuming and requires a detailed safety plan be prepared and followed. Given the complexity of the site conditions and instrument setup distance from the structure an Optech Ilris laser scanner was used. GPS observations on the local control monumentation was collected and tied in to independent offsite control. Using conventional reflectorless total stations, targeted control points were geo-referenced to the project control network. The individual point clouds were merged and a continuous 3D model of the outfall structure was created. Additional color rendering was also performed.

Figure 10-12. Francis E. Walter Dam located in Whitehaven, Pennsylvania. Concrete outfall structure located on the downstream side of the dam is shown at bottom right.

Figure 10-13. Optech Iris Unit positioned in center of river bed at the Francis E. Walter Dam site located in Whitehaven, Pennsylvania.

Figure 10-14. Reflectorless Total Station was utilized to georeference scanner data to project control network

Appendix L
Glossary

L-1. Abbreviations and Acronyms

1D .... One Dimensional
2D .... Two-dimensional
2DRMS .... Twice the distance root mean square
3D .... Three-dimensional
A-E .... Architect-Engineer
A/E/C........................... Architect/Engineer/Construction
ACSM.......................... American Congress on Surveying and Mapping
ADA .... Air Defense Artillery
AFB .... Air Force Base
ALTA .... American Land Title Association
AM/FM........................ Automated Mapping/ Facility Mapping
AOC .... Aircraft Obstruction Surveys
ARP .... Antenna Reference Point
ASCE........................... American Society of Civil Engineers
ASPRS......................... American Society for Photogrammetry and Remote Sensing
BFE.............................. Base Flood Elevation
BLM .... Bureau of Land Management
BS .... Backsight
CADD.......................... Computer Aided Drafting and Design
CAiCE .... Computer Aided Civil Engineering
CALTRANS................ California Department of Transportation
CEFMS........................ Corps of Engineers Financial Management System
COGO.......................... Coordinate Geometry
CONUS. .... CONtinental United States
CORPSCON................ CORPS CONvert
CORS .... Continuously Operating Reference Stations
COR............................. Contracting Officer's Representative
DA .... Department of the Army
DE................................ Difference in Elevation
DEM .... Digital Elevation Model
DOD .... Department of Defense
DOT............................. Department of Transportation
DFARS. .... Defense Federal Acquisition Regulation Supplement
DGPS........................... Differential Global Positioning System
DTM .... Digital Terrain Model
EAC............................. Echelons Above Corps
EDM .... Electronic Distance Measurement
EFARS......................... Engineer Federal Acquisition Regulation Supplement
EM .... Engineer Manual
ERM .... Elevation Reference Mark
ERDC .... Engineer Research and Development Center
E&D. .... Engineering and Design
FA................................ Field Artillery
FAA............................. Federal Aviation Administration
FAC .... Florida Administrative Code

FAR .... Federal Acquisition Regulations
FAR .... Federal Aviation Regulation
FEMA .... Federal Emergency Management Agency
FFP .... Firm Fixed Price
FGCS .... Federal Geodetic Control Subcommittee
FGDC .... Federal Geographic Data Committee
FIRM .... Flood Insurance Rate Map
FIS .... Flood Insurance Study
FLSA .... Fair Labor Standards Act
FM .... Field Manual
FMSFIE .... Facility Management Standard for Facilities, Infrastructure, and Environment
FOA .... Field Operating Activity
FS................................. Foresight
G&A .... General and Administrative
GDOP .... Geometric Dilution of Position
GIS............................... Geographic Information System
GPS.............................. Global Positioning System
GRS 80 .... Geodetic Reference System of 1980
GS .... General Support
GSA .... General Services Administration
GZD.............................. Grid Zone Designator
HARN .... High Accuracy Regional Networks
HI................................. Height of Instrument
HDOP .... Horizontal Dilution of Position
HPGN .... High Precision Geodetic Networks
HR .... Height of Reflector
HT................................ Height of Target
HTRW .... Hazardous, Toxic, or radioactive Waste
HQUSACE .... Headquarters, US Army Corps of Engineers
IDC. .... Indefinite Delivery Contract
IERS .... International Earth Rotation Service
IGE .... Independent Government Estimate
IGLD 55 .... International Great Lakes Datum of 1955
IGLD 85 .... International Great Lakes Datum of 1985
ILS .... Instrument Landing System
INT .... Intersection
ITL............................... Information Technology Lab
ITRF .... International Terrestrial Reference Frame
JTR .... Joint Travel Regulation
KO .... Contracting Officer
LCC .... Lambert Conformal Conic
LEC .... Linear Error of Closure
LIDAR.......................... LIght Detection And Ranging
LWRP........................... Low Water Reference Plane
MACOM .... Major Army Command
MDL .... MicroStation Design Language
MGRS........................... Military Grid-Reference System
MHW............................ Mean High Water
MLLW.......................... Mean Lower Low Water
MLRS .... Multiple Launch Rocket System
MLS.............................. Microwave Landing System

MSL............................. Mean Sea Level
MSL1912...................... Mean Sea Level Datum of 1912
NAD 27 .... North American Datum of 1927
NAD 83 .... North American Datum of 1983
NADCON .... North American Datum Conversion
NAS............................. National Airspace System
NAVAID .... Navigation Aid
NAVD 88 .... North American Vertical Datum 1988
NDGPS........................ Nationwide Differential GPS
NFIP .... National Flood Insurance Program
NGRS .... National Geodetic Reference System
NGS .... National Geodetic Survey
NGVD 29 .... National Geodetic Vertical Datum 1929
NMAS .... National Map Accuracy Standard
NMP .... National Mapping Program
NOAA .... National Oceanic and Atmospheric Administration
NOS .... National Ocean Service
NSRS........................... National Spatial Reference System
NSSDA........................ National Standard for Spatial Data Accuracy
NVCN.......................... National Vertical Control Network
OCONUS .... Outside the Continental United States
OHWM........................ Ordinary High Water Mark
OPUS........................... On-Line Positioning User Service
OTF .... On-the-Fly
P&S .... Plans and Specifications
PADS........................... Position and Azimuth Determination System
PBM .... Permanent Benchmark
PDOP........................... Position Dilution of Position
PDSC........................... Professional Development Support Center
PI .... Point of Intersection
PLGR........................... Precise Lightweight Geodetic Receiver
PM .... Project Manager or Management
POB .... Point of Beginning
POI .... Point on Line
POT .... Point of Tangency
PPRTK .... Post-Processed Real-Time Kinematic
ppm.............................. Parts per Million
PR&C .... Purchase Request & Commitment
PRIP .... Plant Replacement and Improvement Program
PROSPECT .... Proponent Sponsored Engineer Corps Training
PVT .... Point of Vertical Tangent
QA .... Quality Assurance
QC .... Quality Control
RFP.............................. Request for Proposal
RMS .... Root mean Square
RMSE.......................... Root Mean Square Error
RTK............................. Real Time Kinematic
SCP.............................. Survey Control Point
SDSFIE........................ Spatial Data Standard for Facilities, Infrastructure, and Environment
SDTS .... Spatial Data Transfer Standard
SI .... International System of Units

SOW .... Scope or Statement of Work
SPCE .... Survey Planning and Coordination Element
SPCS .... State Plane Coordinate System
TA................................ Target Acquisition
TBM .... Temporary Benchmark
TDS .... Tripod Data Systems
TDSE........................... Touchdown Zone Elevation
TEC .... Topographic Engineering Center
TIN .... Triangular Irregular Network
TM............................... Transverse Mercator
TGO............................. Trimble Geomatics Office
TP .... Turning Point
TSC.............................. Trimble Survey Controller
US................................ United States
USACE .... US Army Corps of Engineers
USARC........................ US Army Reserve Center
USC&GS .... US Coast & Geodetic Survey
USCG .... US Coast Guard
USFS .... US Forest Service
USGS........................... US Geological Survey
USNAVOCEANO........ US Navy Oceanographic Office
USNG .... US National Grid
UTM .... Universal Transverse Mercator
VDOP .... Vertical Dilution of Position
VERTCON .... VERTical CONversion
VLBI............................ Very-Long-Baseline-Interferometry
WAAS .... Wide Area Augmentation System
WGS 84 .... World Geodetic System of 1984
WRDA......................... Water Resources Development Act
XREF........................... External Reference
ZD................................ Zenith Distance

L-2. Terms

Absolute or Autonomous GPS
Operation with a single receiver for a desired position. This receiver may be positioned to be stationary over a point. This mode of positioning is the most common military and civil application.

Accuracy
The degree to which an estimated (mean) value is compatible with an expected value. Accuracy implies the estimated value is unbiased.

Adjustment
Adjustment is the process of estimation and minimization of deviations between measurements and a mathematical model.

Altimeter
An instrument that measures elevation differences usually based on atmospheric pressure measurements.

Altitude
The vertical angle between the horizontal plane of the observer and a directional line to the object.

Angle of Depression
A negative altitude.

Angle of Elevation
A positive altitude.

Angular Misclosure
Difference in the actual and theoretical sum of a series of angles.

Archiving
Storing of documents and information.

Astronomical Latitude
Angle between the plumb line and the plane of celestial equator. Also defined as the angle between the plane of the horizon and the axis of rotation of the earth. Astronomical latitude applies only to positions on the earth and is reckoned from the astronomic equator, north and south through 90E. Astronomical latitude is the latitude that results directly from observations of celestial bodies, uncorrected for deflection of the vertical.

Astronomical Longitude
Arbitrarily chosen angle between the plane of the celestial meridian and the plane of an initial meridian. Astronomical longitude is the longitude that results directly from observations on celestial bodies, uncorrected for deflection of the vertical.

Astronomical Triangle
A spherical triangle formed by arcs of great circles connecting the celestial pole, the zenith and a celestial body. The angles of the astronomical triangles are: at the pole, the hour angle; at the celestial body, the parallactic angle; at the zenith, the azimuth angle. The sides are: pole to zenith, the co-latitude; zenith to celestial body, the zenith distance; and celestial body to pole, the polar distance.

Atmospheric Refraction
Refraction of electromagnetic radiation through the atmosphere causing the line-of-sight to deviate from a straight path. Mainly temperature and pressure conditions determine the magnitude and direction of curvature affecting the path of light from a source. Refraction causes the ray to follow a curved path normal the surface gradient.

Azimuth
The horizontal direction of a line clockwise from a reference plane, usually the meridian. Often called forward azimuth to differentiate from back azimuth.

Azimuth Angle
The angle less than 180° between the plane of the celestial meridian and the vertical plane with the observed object, reckoned from the direction of the elevated pole. In astronomic work, the azimuth angle is the spherical angle at the zenith in the astronomical triangle, which is composed of the pole, the zenith and the star. In geodetic work, it is the horizontal angle between the celestial pole and the observed terrestrial object.

Azimuth Closure
Difference in arc-seconds of the measured or adjusted azimuth value with the true or published azimuth value.

Backsight
A sight on a previously established traverse or triangulation station and not the closing sight on the traverse. A reading on a rod held on a point whose elevation has been previously determined.

Barometric Leveling
Determining differences of elevation from measured differences of atmospheric pressure observed with a barometer. If the elevation of one station above a datum is known, the approximate elevations of other station can be determined by barometric leveling. Barometric leveling is widely used in reconnaissance and exploratory surveys.

Baseline
Resultant three-dimensional vector between any two stations with respect to a given coordinate system. The primary reference line in a construction system.

Base net
The primary baseline used for densification of survey stations to form a network.

Base Points
The beginning points for a traverse that will be used in triangulation or trilateration.

Base Control
The horizontal and vertical control points and coordinates used to establish a base network. Base control is determined by field surveys and permanently marked or monumented for further surveys.

Bearing
The direction of a line with respect to the meridian described by degrees, minutes, and seconds within a quadrant of the circle. Bearings are measured clockwise or counterclockwise from north or south, depending on the quadrant.

Benchmark
A permanent material object, natural or artificial, on a marked point of known elevation.

Best Fit
To represent a given set of points by a smooth function, curve, or surface which minimizes the deviations of the fit.

Bipod
A two-legged support structure for an instrument or survey signal at a height convenient for the observer.

Bluebook
Another term for the "FGCS Input Formats and Specifications of the National Geodetic Data Base".

Blunder
A mistake or gross error.

Bureau International de l'Heure
The Bureau was founded in 1919 and its offices since then have been at the Paris Observatory. By an action of the International Astronomical Union, the BIH ceased to exist on 1 January 1988 and a new organization, the International Earth Rotation Service (IERS) was formed to deal with determination of the Earth's rotation.

Cadastral Survey
Relates to land boundaries and subdivisions, and creates units suitable for transfer or to define the limitations of title. The term cadastral survey is now used to designate the surveys of the public lands of the US, including retracement surveys for identification and resurveys for the restoration of property lines; the term can also be applied properly to corresponding surveys outside the public lands, although such surveys are usually termed land surveys through preference.

Calibration
Determining the systematic errors in an instrument by comparing measurements with correct values. The correct value is established either by definition or by measurement with a device that has itself been calibrated or of much higher precision.

Cartesian Coordinates
A system with its origin at the center of the earth and the x and y and z axes in the plane of the equator. Typically, the x-axis passes through the meridian of Greenwich, and the z-axis coincides with the earth's axis of rotation. The three axes are mutually orthogonal and form a right-handed system.

Cartesian System
A coordinate system consisting of axes intersecting at a common point (origin). The coordinate of a point is the orthogonal distance between that point and the hyperplane determined by all axes. A Cartesian coordinate system has all the axes intersecting at right angles, and the system is called a rectangular.

Celestial Equator
A great circle on the celestial sphere with equidistant points from the celestial poles. The plane of the earth's equator, if extended, would coincide with that of the celestial equator.

Celestial pole
A reference point at the point of intersection of an indefinite extension of the earth's axis of rotation and the apparent celestial sphere.

Celestial sphere
An imaginary sphere of infinite radius with the earth as a center. It rotates from east to west on a prolongation of the earth's axis.

Central Meridian
A line of constant longitude at the center of a graticule. The central meridian is used as a base for constructing the other lines of the graticule. The meridian is used as the y-axis in computing tables for a State Plane Coordinate system. That line, on a graticule, which represents a meridian and which is an axis of symmetry.

Chain
Equal to 66 feet or 100 links. The unit of length prescribed by law for the survey of the US public lands. One acre equals 10 square chains.

Chained Traverse
Observations and measurements performed with tape.

Chaining
Measuring distances on the ground with a graduated tape or with a chain.

Chart Datum
Reference surface for soundings on a nautical chart. It is usually taken to correspond to a low water elevation, and its depression below mean sea level is represented by the symbol Z_o. Since 1989, chart datum has been implemented to mean lower low water for all marine waters of the US its territories, Commonwealth of Puerto Rico and Trust Territory of the Pacific Islands.

Chi-square Testing
Non-parametric statistical test used to classify the shape of the distribution of the data.

Chronometer
A portable timekeeper with compensated balance, capable of showing time with extreme precision and accuracy.

Circle Position
A prescribed setting (reading) of the horizontal circle of a direction theodolite, to be used for the observation on the initial station of a series of stations that are to be observed.

Circuit Closure
Difference between measured or adjusted value and the true or published value.

Clarke 1866 Ellipsoid
The reference ellipsoid used for the NAD 27 horizontal datum. It is a non-geocentric ellipsoid formerly used for mapping in North America.

Closed Traverse
Starts and ends at the same point or at stations whose positions have been determined by other surveys.

Collimation
A physical alignment of a survey target or antenna over a mark or to a reference line.

Collimation Error
The angle between the actual line of sight through an optical instrument and an alignment.

Compass Rule
The correction applied to the departure (or latitude) of any course in a traverse has the same ratio to the total misclosure in departure (or latitude) as the length of the course has to the total length of the traverse.

Confidence Level

Statistical probability (in percent) based on the standard deviation or standard error associated with the normal probability density function. The confidence level is assigned according to an expansion factor multiplied by the magnitude of one standard error. The expansion factor is based on values found in probability tables at a chosen level of significance.

Conformal
Map projection that preserves shape.

Contour
An imaginary line on the ground with all points at the same elevation above or below a specified reference surface.

Control
Data used in geodesy and cartography to determine the positions and elevations of points on the earth's surface or on a cartographic representation of that surface. A collective term for a system of marks or objects on the earth or on a map or a photograph whose positions or elevation are determined.

Control Densification
Addition of control throughout a region or network.

Control Monuments
Existing local control or benchmarks that may consist of any Federal, state, local or private agency points.

Control Point
A point with assigned coordinates is sometimes used as a synonym for control station. However, a control point need not be realized by a marker on the ground.

Control Survey
A survey which provides coordinates (horizontal or vertical) of points to which supplementary surveys are adjusted.

Control Traverse
A survey traverse made to establish control.

Conventional Terrestrial Pole (CTP)
The origin of the WGS 84 Cartesian system is the earth's center of mass. The Z-axis is parallel to the direction of the CTP for polar motion, as defined by the Bureau of International de l'Heure (BIH), and equal to the rotation axis of the WGS 84 ellipsoid. The X-axis is the intersection of the WGS 84 reference meridian plane and the CTP's equator, the reference meridian being parallel to the zero meridian defined by the BIH and equal to the X-axis of the WGS 84 ellipsoid. The Y-axis completes a right-handed, earth-centered, earth-fixed orthogonal coordinate system, measured in the plane of the CTP equator 90 degrees east of the X-axis and equal to the Y-axis of the WGS 84 ellipsoid.

Coordinate Transformation
A mathematical process for obtaining a modified set of coordinates through some combination of rotation of coordinate axes at their point of origin, change of scale along coordinate axes, or translation through space

CORPSCON
(Corps Convert) Software package (based on NADCON) capable of performing coordinate transformations between NAD 83 and NAD 27 datums.

Crandall Method
Traverse misclosure in azimuth or angle is first distributed in equal portions to all the measured angles. The adjusted angles are then held fixed and all remaining coordinate corrections distributed among the distance measurements.

Cross sections
A survey line run perpendicular to the alignment of a project, channel or structure.

Curvature
The rate at which a curve deviates from a straight line. The parametric vector described by dt/ds, where t is the vector tangent to a curve and s is the distance along that curve.

Datum
Any numerical or geometrical quantity or set of such quantities which serve as a reference or base for other quantities.

Declination
The angle, at the center of the celestial sphere, between the plane of the celestial equator and a line from the center to the point of interest (on a celestial body).

Deflection of the Vertical
The spatial angular difference between the upward direction of a plumb line and the normal to the reference ellipsoid. Often expressed in two orthogonal components in the meridian and the prime vertical directions.

Deflection Traverse
Direction of each course measured as an angle from the direction of the preceding course.

Deformation Monitoring
Observing the movement and condition of structures by describing and modeling its change in shape.

Departure
The orthogonal projection of a line onto an east-west axis of reference. The departure of a line is the difference of the meridional distances or longitudes of the ends of the line.

Differential GPS
Process of measuring the differences in coordinates between two receiver points, each of which is simultaneously observing/measuring satellite code ranges and/or carrier phases from the NAVSTAR GPS constellation. Relative positioning with GPS can be performed by a static or kinematic modes.

Differential Leveling
The process of measuring the difference of elevation between any two points by spirit leveling.

Direction
The angle between a line or plane and an arbitrarily chosen reference line or plane. At a triangulation station, observed horizontal angles are referred to a common reference line and termed horizontal direction. A line, real or imaginary, pointing away from some specified point or locality toward another point. Direction has two meanings: that of a numerical value and that of a pointing line.

Direct Leveling
The determination of differences of elevation through a continuous series of short horizontal lines. Vertical distances from these lines to adjacent ground marks are determined by direct observations on graduated rods with a leveling instrument equipped with a spirit level.

Distance Angle
An angle in a triangle opposite a side used as a base in the solution of the triangle, or a side whose length is to be computed.

Dumpy Level
The telescope permanently attached to the leveling base, either rigidly to by a hinge that can be manipulated by a micrometer screw.

Earth-Centered Ellipsoid
Center at the Earth's center of mass and minor semi-axis coincident with the Earth's axis of rotation.

Easting
The distance eastward (positive) or westward (negative) of a point from a particular meridian taken as reference.

Eccentricity
The ratio of the distance from the center of an ellipse to its focus on the major semi-axis.

Electronic Distance Measurement (EDM)
Timing or phase comparison of electro-magnetic signal to determine an interferometric distance.

Elevation
The height of an object above some reference datum.

Ellipsoid
Formed by revolving an ellipse about its minor semi-axis. The most commonly used reference ellipsoids in North America are: Clarke 1866, Geodetic Reference System of 1980 (GRS 80), World Geodetic System of 1972 (WGS 72) and World Geodetic System of 1984 (WGS 84).

Ellipsoid height
The magnitude h of a point above or below the reference ellipsoid measured along the normal to the ellipsoid surface.

Error
The difference between the measured value of a quantity and the theoretical or defined value of that quantity.

Error Ellipse
An elliptically shaped region with dimensions corresponding to a certain probability at a given confidence level.

Error of Closure
Difference in the measured and predicted value of the circuit along the perimeter of a geometric figure.

Finite Element Method
Obtaining an approximate solution to a problem for which the governing differential equations and boundary conditions are known. The method divides the region of interest into numerous, interconnected sub-regions (finite elements) over which simple, approximating functions are used to represent the unknown quantities.

Fixed Elevation
Adopted as a result of tide observations or previous adjustment of spirit leveling, and which is held at its accepted value in any subsequent adjustment.

Foresight
An observation to the next instrument station. The reading on a rod that is held at a point whose elevation is to be determined.

Frequency
The number of complete cycles per second existing in any form of wave motion.
Geodesic Line
Shortest distance between any two points on any mathematically defined surface.

Geodesy
Determination of the time-varying size and figure of the earth by such direct measurements as triangulation, leveling and gravimetric observations.

Geodetic Control
Established and adjusted horizontal and/or vertical control in which the shape and size of the earth have been considered in position computations.

Geodetic Coordinates
Angular latitudinal and longitudinal coordinates defined with respect to a reference ellipsoid.

Geodetic Height
See Ellipsoid height.

Geodetic Latitude
The angle which the normal at a point on the reference ellipsoid makes with the plane of the equator.

Geodetic Leveling
The observation of the differences in elevation by means of a continuous series of short horizontal lines of sight.

Geodetic Longitude
The angle subtended at the pole between the plane of the geodetic meridian and the plane of a reference meridian (Greenwich).

Geodetic North
Direction tangent to a meridian pointing toward the pole defining astronomic north, also called true north.

Geodetic Reference System of 1980
Reference ellipsoid used to establish the NAD 83 system of geodetic coordinates.

Geoid
An equipotential surface of the gravity field approximating the earth's surface and corresponding with mean sea level in the oceans and its extension through the continents.

GPS (Global Positioning System)
DoD satellite constellation providing range, time, and position information through a GPS receiver system.

Gravimeter
Instrument for measuring changes in gravity between two points.

Gravity
Combined acceleration potential of an object due to gravitation and centrifugal forces.

Greenwich Meridian
The astronomic meridian through the center of the Airy transit instrument of the Greenwich Observatory, Greenwich, England. By international agreement in 1884, the Greenwich meridian was adopted as the meridian from which all longitudes, worldwide, would be calculated.

Grid Azimuth
The angle in the plane of projection between a straight line and the line (y-axis) in a plane rectangular coordinate system representing the central meridian. While essentially a map-related quantity, a grid azimuth may, by mathematical processes, be transformed into a survey- related or ground-related quantity.

Grid Inverse
The computation of length and azimuth from coordinates on a grid.

Grid Meridian
Line parallel to the line representing the central meridian or y-axis of a grid on a map. The map line parallel to the line representing the y-axis or central meridian in a rectangular coordinate system.

Gunter's Chain
A measuring device once used in land surveying. It was composed of 100 metallic links fastened together with rings. The total length of the chain is 66 feet. Also called a four-pole chain.

Gyrotheodolite
A gyroscopic device used to measure azimuth that is built-in or attached to a theodolite.

Histogram
A graphical representation of relative frequency of an outcome partitioned by class interval. The frequency of occurrence is indicated by the height of a rectangle whose base is proportional to the class interval.

Horizontal Control
Determines horizontal positions with respect to parallels and meridians or to other lines of reference.

Hour Circle
Any great circle on the celestial sphere whose plane is perpendicular to the plane of the celestial equator.

Index Error
A systematic error caused by deviation of an index mark or zero mark on an instrument having a scale or vernier, so that the instrument gives a non-zero reading when it should give a reading of zero. The distance error from the foot of a leveling rod to the nominal origin (theoretical zero) of the scale.

Indirect Leveling
The determination of differences of elevation from vertical angles and horizontal distances.

Interior Angle
An angle between adjacent sides of a closed figure and lying on the inside of the figure. The three angles within a triangle are interior angles.

International Foot
Defined by the ratio 30.48/100 meters.

International System of Units (SI)
A self-consistent system of units adopted by the general Conference on Weights and Measures in 1960 as a modification of the then-existing metric system.

Interpolation Method
Determination of a intermediate value between given values using a known or assumed rate of change of the values between the given values.

Intersection
Determining the horizontal position of a point by observations from two or more points of known position. Thus measuring directions or distances that intersect at the station being located. A station whose horizontal position is located by intersection is known as an intersection station.

Intervisibility
When two stations are visible to each other in a survey net.

Invar
An alloy of iron containing nickel, and small amounts of chromium to increase hardness, manganese to facilitate drawing, and carbon to raise the elastic limit, and having a very low coefficient of thermal expansion (about 1/25 that of steel).

Isogonic Chart
A system of isogonic lines, each for a different value of the magnetic declination.

Isogonic Line
A line drawn on a chart or map and connecting all points representing points on the earth having equal magnetic declination at a given time.

Laplace Azimuth
A geodetic azimuth derived from an astronomic azimuth by use of the Laplace equation.

Laplace Condition
Arises from the fact that a deflection of the vertical in the plane of the prime vertical will give a difference between astronomic and geodetic longitude and between astronomic and geodetic azimuth. Conversely, the observed differences between astronomic and geodetic values of the longitude and of the azimuth may both be used to determine the deflection in the plane of the prime vertical.

Laplace Equation
Expresses the relationship between astronomic and geodetic azimuths in terms of astronomic and geodetic longitudes and geodetic latitude.

Laplace Station
A triangulation or traverse station at which a Laplace azimuth is determined. At a Laplace station both astronomic longitude and astronomic azimuth are determined.

Least Count
The finest reading that can be made directly (without estimation) from a vernier or micrometer.

Least Squares Adjustment
The adjustment of the values of either the measured angles or the measured distances in a traverse using the condition that the sum of the squares of the residuals is a minimum.

Level
Any device sensitive to the direction of gravity and used to indicate directions perpendicular to that of gravity at a point.

Level Datum
A level surface to which elevations are referred. The generally adopted level datum for leveling in the US is mean sea level. For local surveys, an arbitrary level datum is often adopted and defined in terms of an assumed elevation for some physical mark.

Level Net
Lines of spirit leveling connected together to form a system of loops or circuits extending over an area.

Line of Sight
The line extending from an instrument along which distant objects are seen, when viewed with a telescope or other sighting device.

Local Coordinate System
Where the coordinate system origin is assigned arbitrary values and is within the region being surveyed and used principally for points within that region.

Local Datum
Defines a coordinate system that is used only over a region of very limited extent.

Loop Traverse
A closed traverse that starts and ends at the same station. A pattern of measurements in the field, so that the final measurement is made at the same place as the first measurement.

Magnetic Bearing
The angle with respect to magnetic north or magnetic south stated as east or west of the magnetic meridian.

Magnetic Meridian
The vertical plane through the magnetic pole including the direction, at any point, of the horizontal component of the Earth's magnetic field.

Major Semi-Axis
The line from the center of an ellipse to the extremity of the longest diameter. The term is also used to mean the length of the line.

Map
A conventional representation, usually on a plane surface and at an established scale, of the physical features (natural, artificial, or both) of a part or whole of the Earth's surface by means of signs and symbols and with the means of orientation indicated.

Map Accuracy
The accuracy with which a map represents. Three types of error commonly occur on maps: errors of representation, which occur because conventional signs must be used to represent natural or man-made features such as forests, buildings and cities; errors of identification, which occur because a non-existent feature is shown or is misidentified; and errors of position, which occur when an object is shown in the wrong position. Errors of position are commonly classified into two types: errors of horizontal location and errors of elevation. A third type, often neglected, is errors of orientation.

Map Scale
The ratio of a specified distance on a map to the corresponding distance in the mapped object.

Mean Angle
Average value of the angles.

Mean Lower Low Water (MLLW)
The average height of all lower low waters recorded over a 19-year period.
Mean Sea Level Datum
Adopted as a standard datum for heights or elevations. The Sea Level Datum of 1929, the current standard for geodetic leveling in the United States, is based on tidal observations over a number of years at various tide stations along the coasts.

Metric Unit
Belonging to or derived from the SI system of units.

Micrometer
In general, any instrument for measuring small distances very accurately. In astronomy and geodesy, a device, for attachment to a telescope or microscope, consisting of a mark moved across the field of view by a screw connected to a graduated drum and vernier. If the mark is a hair-like filament, the micrometer is called a filar micrometer.

Minor Semi-Axis
The line from the center of an ellipse to the extremity of the shortest diameter. I.e., one of the two shortest lines from the center to the ellipse. The term is also used to mean the length of the line.

Misclosure
The difference between a computed and measured value.

Monument
A physical object used as an indication of the position on the ground of a survey station.

NADCON
The National Geodetic Survey developed the conversion program NADCON (North American Datum Conversion) to convert to and from North American Datum of 1983. The technique used is based on a bi-harmonic equation classically used to model plate deflections. NADCON works exclusively in geographical coordinates (latitude/longitude).

Nadir
The point directly beneath the instrument and directly opposite to the zenith or the lowest point.

National Geodetic Vertical Datum 1929
Formerly adopted as the standard geodetic datum for heights, based on an adjustment holding 26 primary tide stations in North America fixed.

National Map Accuracy Standards
Specifications of the accuracy required of topographic maps published by the US at various scales.

National Tidal Datum Epoch
A period of 19 years adopted by the National Ocean Survey as the period over which observations of tides are to be taken and reduced to average values for tidal datums.

Network
Interconnected system of surveyed points.

Non-SI units
Units of measurement not associated with International System of Units (SI).

North American Datum of 1927
Formerly adopted as the standard geodetic datum for horizontal positioning. Based on the Clarke ellipsoid of 1866, the geodetic positions of this system are derived from a readjustment of survey observations throughout North America.

North American Datum of 1983
Adopted as the standard geodetic datum for horizontal positioning. Based on the Geodetic Reference System of 1980, the geodetic positions of this system are derived from a readjustment of survey observations throughout North America.

North American Vertical Datum of 1988
Adopted as the standard geodetic datum for heights.

Northing
A linear distance, in the coordinate system of a map grid, northwards from the east-west line through the origin (or false origin).

Open Traverse
Begins from a station of known or adopted position, but does not end upon such a station.

Optical Micrometer
Consists of a prism or lens placed in the path of light entering a telescope and rotatable, by means of a graduated linkage, about a horizontal axis perpendicular to the optical axis of the telescope axis. Also called an optical-mechanical compensator. The device is usually placed in front of the objective of a telescope, but may be placed immediately after it. The parallel-plate optical micrometer is the form usually found in leveling instruments.

Optical Plummet
A small telescope having a 90° bend in its optical axis and attached to an instrument in such a way that the line of sight proceeds horizontally from the eyepiece to a point on the vertical axis of the instrument and from that point vertically downwards. In use, the observer, looking into the plummet, brings a point on the instrument vertically above a specified point (usually a geodetic or other mark) below it.

Order of Accuracy
Defines the general accuracy of the measurements made in a survey. The order of accuracy of surveys are divided into four classes labeled: First Order, Second Order, Third Order and Fourth or lower order.

Origin
That point in a coordinate system which has defined initial coordinates and not coordinates determined by measurement. This point is usually given the coordinates (0,0) in a coordinate system in the plane and (0,0,0) in a coordinate system in space.

Orthometric Height
The elevation H of a point above or below the geoid.

Parallax
The apparent displacement of the position of a body, with respect to a reference point or system, caused by a shift in the point of observation.

Philadelphia Leveling Rod
Having a target but with graduations so styled that the rod may also be used as a self-reading leveling rod. Also called a Philadelphia rod. If a length greater than 7 feet is needed, the target is clamped at 7 feet and raised by extending the rod. When the target is used, the rod is read by vernier to 0.001 foot. When the rod is used as a self-reading leveling rod, the rod is read to 0.005 foot.

Photogrammetry
Deducing the physical dimensions of objects from measurements on photographs of the objects.

Picture Point
A terrain feature easily identified on an aerial photograph and whose horizontal or vertical position or both have been determined by survey measurements. Picture points are marked on the aerial photographs by the surveyor, and are used by the photomapper.

Planetable
A field device for plotting the lines of a survey directly from observations. It consists essentially of a drawing board mounted on a tripod, with a leveling device designed as part of the board and tripod.

Planimetric Feature
Item detailed on a planimetric map.

Plumb Line
The direction normal to the geopotential field. The continuous curve to which the gradient of gravity is everywhere tangential.

Positional Error
The amount by which the actual location of a cartographic feature fails to agree with the feature's true position.

Post-Processed Real-Time Kinematic GPS
GPS carrier phase positioning performed without real-time data link and solution.

Precision
The amount by which a measurement deviates from its mean.

Prime Meridian
The meridian of longitude 0°, used as the origin for measurement of longitude. The meridian of Greenwich, England, is almost universally used for this purpose.

Prime Vertical
The vertical circle through the east and west points of the horizon. It may be true, magnetic, compass or grid depending upon which east or west points are involved.

Project Control
Control used for a specific project.

Project Datum
Datum used for a specific project.

Projection
A set of functions, or the corresponding geometric constructions, relating points on one surface to points on another surface. A projection requires every point on the first surface to correspond one-to-one to points on the second surface.

Quadrangle
Consisting of four specified points and the lines or line segments on which they lie. The quadrangle and the quadrilateral differ in that the quadrangle is defined by four specified angle points, the quadrilateral by four specified lines or line-segments.
Random Error
Randomly distributed deviations from the mean value.

Range Pole
A simple rod fitted with a sharp-pointed, shoe of steel and usually painted alternately in red and white bands at 1-foot intervals.

Readings
The observed value obtained by noting and/or recording scales.

Real-time
An event or measurement reported or recorded at the same time as the event is occurring through the absence of delay in getting, sending and receiving data.

Real-Time Kinematic GPS
GPS carrier phase processing and positioning in real-time.

Reciprocal Leveling
Measuring vertical angles or making rod readings from two instrument positions for the purpose of compensating for the effects of refraction.

Rectangular Coordinate Systems
Coordinates on any system in which the axes of reference intersect at right angles.

Redundant Measurements
Taking more measurements than are minimally required for a unique solution.

Reference Meridian, True
Based on the astronomical meridian.

Reference Meridian, Magnetic
Based on the magnetic pole.

Reference Point
Used as an origin from which measurements are taken or to which measurements are referred.

Refraction
The bending of rays by the substance through which the rays pass. The amount and direction of bending are determined by its refractive index.

Relative Accuracy
Indicated by the dimensions of the relative confidence ellipse between two points. A quantity expressing the effect of random errors on the location of one point or feature with respect to another.

Repeating Theodolite
Designed so that the sum of successive measurements of an angle can be read directly on the graduated horizontal circle.

Resection
Determining the location of a point by extending lines of known direction to two other known points.

Sexagesimal System
Notation by increments of 60. As the division of the circle into 360°, each degree into 60 minutes, and each minute into 60 seconds.

Set-up
In general, the situation in which a surveying instrument is in position at a point from which observations are made.

Spheroid
Used as a synonym for ellipsoid.

Spirit Level
A closed glass tube (vial) of circular cross section. Its center line forms a circular arc with precise form and filled with ether or liquid of low viscosity, with enough free space left for a bubble of air or gas.

Stadia Constant
The sum of the focal length of a telescope and the distance from the vertical axis of the instrument on which the telescope is mounted to the center of the objective lens-system.

Stadia Traverse
Distances are determined using a stadia rod. A stadia traverse is suited to regions of moderate relief with an adequate network of roads. If done carefully, such a traverse can establish elevations accurate enough for compiling maps with any contour interval now standard.

Standard Error
The standard deviation of the errors associated with physical measurements of an unknown quantity, or statistical estimates of an unknown quantity or of a random variable.

Systematic Error
Errors that affect the position (bias) of the mean. Systematic errors are due to unmodeled affects on the measurements that have a constant or systematic value.

State Plane Coordinate System (SPCS)
A planar reference coordinate system used in the United States.

Strength of Figure
A number relating the precision in positioning with the geometry with which measurements are made.

Subtense Bar
A bar with two marks at a fixed, known distance apart used for determining the horizontal distance from an observer by means of the measuring the angle subtended at the observer between the marks.

Taping
Measuring a distance on the using a surveyor's tape.
Three-wire Leveling
The scale on the leveling rod is read at each of the three lines and the average is used for the final result.

Topographic Map
A map showing the horizontal and vertical locations of the natural and man-made features represented and the projected elevations of the surroundings.

Transformation
Converting a position from one coordinate system to another.

Transit
The apparent passage of a star or other celestial body across a defined line of the celestial sphere.

Transit Rule
The correction to be applied to the departure (or latitude) of any course has the same ratio to the total misclosure in departure (or latitude) as the departure (latitude) of the course has to the arithmetical sum of all the departures (latitudes) in the traverse. The transit rule is often used when it is believed that the misclosure is caused less by errors in the measured angles than by errors in the measured distances.

Transverse Mercator Projection
Mercator map projection calculated for a cylinder with axis in the equatorial plane.

Traverse
A sequence of points along which surveying measurements are made.

Triangulation
Determination of positions in a network by the measurement of angles between stations.

tribrach
The three-armed base, of a surveying instrument, in which the foot screws used in leveling the instrument are placed at the ends of the arms. Also called a leveling base or leveling head.

Trigonometric heighting
The trigonometric determination of differences of elevation from observed vertical angles and measured distances.

Trilateration
Determination of positions in a network by the measurement of distances between stations using the intersection of two or more distances to a point.

Universal Transverse Mercator
A worldwide metric military coordinate system.

US Coast & Geodetic Survey (USC&GS)
Now known as National Ocean Service (NOS).

US Survey Foot
The unit of length defined by 1200/3937 m

Variance-Covariance Matrix
A matrix whose elements along the main diagonal are called the variances of the corresponding variables; the elements off the main diagonal are called the covariances.

Vernier
An auxiliary scale used in reading a primary scale. The total length of a given number of divisions on a vernier is equal to the total length of one more or one less than the same number of divisions on the primary scaled.

VERTCON
Acronym for vertical datum conversion. VERTCON is the computer software that converts orthometric heights between NGVD 29 to NAVD 88.

Vertical Angle
An angle in a vertical plane either in elevation or depression from the horizontal.

Vertical Circle
A graduated scale mounted on an instrument used to measure vertical angles.

Vertical Datum
Any level surface used as a reference for elevations. Although a level surface is not a plane, the vertical datum is frequently referred to as the datum plane.

World Geodetic System of 1984
Adopted as the standard geodetic datum for GPS positioning. Based on the World Geodetic System reference ellipsoid.

Wye Level
Having the telescope and attached spirit level supported in wyes (Y's) in which it can be rotated about its longitudinal axis (collimation axis) and from which it can be lifted and reversed, end for end. Also called a Y-level and wye-type leveling instrument.

Zenith
The point above the instrument where an extension of a plumb (vertical) line at the observer's position intersects the celestial sphere.

Zenith Angle
Measured in a positive direction downwards from the observer's zenith to the observed target.

Zenith Distance
The complement of the altitude, the angular distance from the zenith of the celestial body measured along a vertical circle.