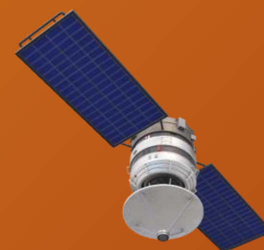
GUIDEBOOK: GNSS IN THE GEOSCIENCES



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GNSS IN GEOSCIENCES

This book introduces the theory and operation of Global Navigation Satellite Systems (GNSS) and Global Positioning Systems (GPS), and the application of GNSS for solving research problems common in the Geosciences. Geodesy will be covered in depth. GPS technology is introduced through a review of the fundamental concepts of coordinate systems and geodesy, followed by an in-depth discussion of signal propagation, signal processing, and the limitations of both handheld and differential GPS units. This is followed by a discussion about measurement strategies and an overview of how GPS is used in the Geosciences.

OUTCOMES

Learning Outcomes

1) Describe and calculate Geodetic Coordinate Systems, Datums, Conversions, and Transformation.

2) Name, describe, and compare traditional georeferencing, mapping, tracking, navigation, and survey techniques.

3) Describe the technology used in Global Navigation Satellite Systems (GNSS), explain how GNSS system works, and what the limitations are for handheld and differential GPS units.

4) Apply GNSS technology and appropriate measurement strategies to design, collect, and analyze research problems common in the Geosciences.

""If you can't do spatial reasoning, then geography becomes memorization."
Dr. Stacey D. Lyle

This book is broken down into the following areas:

- Math
- Geodesy
- Coordinate Transformations and Conversions
- GPS Satellite Signals
- GPS Receivers
- GPS Solutions
- GPS Accuracies
- GPS Applications

VALUE STATEMENT

Establishing a solid information is vital in being able to understand and solve problems in today's geoscience industry. This applies especially for people not directly involved in goesciences, as an understanding of the field will help them better understand the needs of geoscience/GNSS-involved projects.

GEODESY

The purpose of Geodesy is to model the Earth into a sphere, which is much easier to reference in navigation, maps, and most other location-based applications. Upon successfully modelling the Earth's shape into a sphere, coordinate systems are applied to it to create a spheroid model. To move back to matching the Earth's actual shape, this spheroid is then modelled into an ellipsoid to match the compressed shape the Earth has from its revolution around the axis. Once there is an ellipsoid, there are many ways of displaying the Earth's surface features on the ellipsoid, called projections, which are usually tailored to more accurately represent a specific area or display a map feature more prominently. A combination of all the above is called a geodetic datum, formally defined as a model of the size and shape of the Earth, which are also usually tailored to be more accurate in specific areas.

Due to the different ways a map can be drawn, there are different types of north. There is Grid North, which is just directly upwards in a grid-based projection. True North, also called geodetic north, points to the Earth's North Pole. There also Magnetic North, bus as the magnetic North Pole of Earth tends to shift, it is not often used outside of very rough surveying methods.

Azimuths and bearings are a vital way for determining area and direction in grid and degree-based projections, as a location can be found regardless of area shape with just simple trigonometry.

GEOMETRIC: LATITUDE AND LONGITUDE EXPLAINED

Most public and commercial maps function based on latitude and longitude in degrees. Because the Earth is roughly spherical, degrees around a circle is very efficient for finding a set place on Earth. North and South degrees are based on angle from the Equator (centerline around the Earth) and East and West degrees are based from the Prime Meridian (top-to-bottom line). These centerlines are based on the datum used in the area, and as such one place might have different degree coordinates in different reference areas. An example is the Clarke 1866 ellipsoid (used for North America) vs the Airy ellipsoid used in Britain and parts of Europe. However, the standard ellipsoid used for global positioning is WGS84, as it has been determined to be (so far) the best average fit for the entire globe.

PROJECTIONS: STATE PLANE COORDINATE SYSTEM

A prevalent example of using different coordinate systems to have better map fitting for an area is the US State Plane Coordinate System. The State Plane Coordinate System uses different projections per state to preserve correct area and distance. The SPCS uses 2 different projections: Transverse Mercator and Lambert Conformal Conic. States that are more horizontally oriented use Lambert, with more vertical states using Transverse Mercator. These projections best preserve area in their respective direction which allows the states to have maps that more accurately fit them better than a more generalized US projection.

DATUMS:

Datums are datasets that model the shape and size of the Earth. These include various pieces such as gravity maps and topographic surveys to come as close as possible to being true to the actual dimensions of the Earth. There are two main categories of datum: horizontal and vertical.

HORIZONTAL DATUM

Horizontal datums cover distance and area on the surface. In the US, most maps of any type are based from NAD1927 (based on the Clarke 1866 ellipsoid) or NAD1983 (based on the more recently determined GRS80 ellipsoid).

VERTICAL DATUM

Vertical datums cover elevation, depth, and topography in general. The main vertical datums used are NGVD1929 and its successor NAVD1988, which are both based from mean sea level.

Aside from the single type datums, there is a unified datum called TRF2022, which seeks to accurately measure the whole globe, increase precision on elevation using gravity surveys, and generally build on the successes and over the shortcomings of most current datums internationally.

GEOID

A geoid is a model of the Earth designed for accuracy of shape and size on a global scale, with sea level being the determining factor. Geoid sea level disregards the reality of wind, climate, currents,etc. and instead models solely on what the sea level would be based on gravity and the Earth's rotation, even what depth it would be on land.

Geoid12A Hybrid and its successor Geoid12B have been in use for many years as the standard elevation geoid for the US National Geodetic Survey, both being based off of accurate, specific data collected from the U.S. and surrounding territories.

Additionally, work is being done on a new geoid (tentatively) called Geoid2022 which along with TRF2022 is being developed to replace NAD88 and NAVD88 as the primary datum used for mapping and navigation in North America.

DATA CONVERSION AND TRANSFORMATION

Explain moving from Datum to Datum and Geometric to Projected

Coordinate systems for maps can take one of two forms: geometric or projected. Geometric coordinates use the spheroid model of the Earth with degrees serving to orient position. Projected coordinates come from the projection of a flat surface onto the spheroid, so orientation is based off linear units (usually feet or meters).

While working with maps, it is sometimes necessary to convert a coordinate system to either another datum, or a different system on the same datum. There is a process for each of these, respectively called transformation and conversion.

TRANSFORMATION

For converting coordinates to a different datum, a very complex mathematical model is needed. Much outstripping the algebra from conversion, datum transformation is much too unwieldy to be done near manually. The US NGS maintains a tool called NCAT (Coordinate Conversion and Transformation Tool, preceded by NADCON) to transform single points to other datums, and there are many professional tools within GIS software that can convert an entire map. Either way, transformation is a very resource-intensive procedure.

CONVERSION

Converting to or from one type of coordinate system to the other is theoretically more simple, as it simply involves converting degrees to/from the linear unit. 1 degree of latitude/longitude is on average 69 miles/111km, so simple algebra can be used for the conversion. For more specific locations, degrees are either decimal degrees (ex. 45.274 deg.) or Degree/Minute/Second. D/M/S only takes slightly more work, as a degree-minute is 1/60 of a degree, and a degree-second is 1/3600 degrees. The reason that conversion is so simple is that any conversions can only happen with maps based on the same datum, so only the format and not the content has changed.

GNSS SATELLITES

GPS satellites, a subsection of all GNSS satellites, make up only one segment of the GPS solution. The satellites are corrected and maintained by ground control, and end users are able to put the data from both of those to work for positioning using GPS receiver units. Besides the GPS satellite constellation maintained by the US, other similar satellite systems make up the total GNSS system in orbit around Earth. These include Russia's GLONASS and Europe's Galileo, which function on the same base principles.

GPS positioning works via a process called trilateration, which requires at least 4 satellites for a proper solution. The each of the first 3 satellites defines a circular area that roughly coincides with the actual location. The point is found horizontally in a much more accurate manner at the intersection point of all 3 satellite areas. The 4^{th} satellite traces a circle that extends off of the Earth's surface to verify the elevation of the point.

GPS L1, L2, AND L5

GPS satellites send data to receivers over specific radio frequencies, dubbed L1, L2 (and L2C), and L5. The number is associated with their relative power and use, with the exception of L1C, which is currently in development to be more powerful than L5.

TIME TO DISTANCE

As we know the speed of the above radio waves, we can use that to determine the distance between 2 points, that being the satellite and the receiver. As the velocity is set, (barring interference, which is usually corrected for) the amount of time the signal took to travel is directly proportional to the distance travelled.

EPHEMERIS

Along with time-distance calculations, another vital element of GPS positioning is the satellite ephemeris. The ephemeris is essentially a timetable of where a given satellite will be at a given time, considering velocity, orbit, and many other factors. The almanac goes along with this as a rougher but more general set of information about the locations of the GPS satellite constellations as a whole to supplement the ephemeris' individual data.

CODE

How is the code carried or modulated on a frequency?

Within the frequency of any GPS radio signal, the wave is modulated to allow the wave to be in a state of 1 or 0 only. With this, binary data con be sent and received with little room for issue. Aside from navigation, the data sent also verifies satellite ID and security against tampering.

C/A CODE

C/A coding is the legacy method, and current basis for non-military applications. It assigns a pseudo-random modulated pattern on the signal to each satellite, unique to prevent misidentification, which GPS receivers have stored to compare against to find which satellite the signal is coming from.

P- CODE

P-code works off of approximately the same premise, but it is able to much more precisely show position due to its higher complexity. P-code is the basis for most military signals, as it is able to be combined with a W-code signal to introduce encryption.

L2C AND L1C

L2C (and L1C upon implementation) are direct improvements upon the existing L2 and L1 signals. Using a stronger signal with additions such as corrections for atmospheric interference allows for higher performance in all levels of public/commercial positioning needs. (The -C indicates commercial use, as opposed to military.)

GNSS RECEIVERS

Define the types of GPS Receivers:

GNSS/GPS Receivers come in three main categories:

Consumer grade: Consumer receivers have the lowest cost, along with lowest accuracy. For non-professional users, this tier is enough for most applications. These include cell phones, handheld GPS units, and any other less-than-professional-grade units. Accuracy averages at within several dozen meters

Mapping: GPS units used for mapping are more expensive and more accurate, but not to a large degree for either. Mapping GPS units are used for zoning, property staking, and basic cartography. Accuracy averages 1-2 meters.

Geodetic/RTK: RTK (Real Time Kinematic) GPS units are used specifically for collecting the most accurate data possible, with a centimeter-level accuracy on average. They are used for surveying to establish accurate models of the measured area, as well as projects with very sensitive positioning restraints like oil drilling.

PARTS OF GNSS RECEIVER

Engine: In rover-type units, the unit is driven/piloted remotely away from a base station.

Antenna: Receives signal and information from the satellites.

Data Collector/Interface: Controls/processes the input position data.

Memory: Stores points, formatted positioning data, and necessary operating info.

Battery

CONFIGURATIONS

Handheld: The most common type, handheld GPS receives the regular trilateration process. There is more accuracy and correction at higher tiers, but the principle is the same.

Base Station & Rover: This configuration is usually only used with RTK units, as it provides an extra layer of error reduction. The base station stays stationary on a single known/established/published point and references the same satellites as the rover does wherever its moves. As the specific location of the base station is known, and deviation from that can be attributed to interference, which can then be corrected for by the rover unit even as it moves around.

TYPES OF GNSS SOLUTIONS

AUTONOMOUS

Autonomous solutions are based on a single receiver processing the trilateration. This method is used by most GPS units, as the process can usually be repeated enough times to create a an averaged point that is sufficiently close to the real point.

DGPS

DGPS, or Code Differential GPS, is used whenever there is an established point used to correct signal interference, requiring at least 2 units. The process is the same as the base station-rover procedure outlined in the previous section. There can be more than 2 units to create more differences to average into a more precise point.

WAAS

This principle has been extended to many standalone GPS units as well with WAAS (Wide Area Augmentation System). WAAS comprises of a series of base stations spread over the US to serve as differential reference points for GPS units that would not otherwise have one. This serves to increase GPS accuracy across all levels of GPS units in use in the US.

PHASE DIFF

As explained earlier, distancing is done by measuring the velocity against the time the signal takes to travel. However, this solution assumes only entire wavelengths. As the involved wavelengths are quite large (on the order of 10s of meters), precision is lost when the partial wavelength is not considered. Phase differential GPS seeks to solve this, but at great processing cost. It is only available in RTK GPS units due to its complexity. Phase solutions can be either float or fixed, but are initiated with the goal of a fixed solution.

FLOAT SOLUTION

A float solution uses the phase differential algorithm to find partial wavelengths with varying certainty. “Float” refers to a floating point/decimal number, which represent the amount of uncertainty on the more exact position and amount of partial wavelength. While float accuracy is still much more accurate than most types of GPS, it is still outstripped by the fixed solution.

FIXED SOLUTION

The fixed solution is reached by optimal conditions in finding the point, as it finds the number of wavelengths down to a “fixed” number, creating a fixed position with very little uncertainty. This is the most precise type of GPS positioning to date, with accuracy down to millimeters.

GNSS APPLICATIONS

By use of GNSS positioning, we are able to perform many vital processes in the following fields.

SURVEYING AND MAPPING

Topo, Land, Elevation, Geodetic, Construction, Navigation, Standards

GEOLOGY/GEOSCIENCE

Topographic Mapping, Determination of Water/Oil Well Locations

WETLAND

Elevation Maps, Flood/Drainage Mitigation

ENVIRONMENTAL

Phase 1 and Phase 2 Environmental Reports, for establishing environmentally hazardous areas.

HYDROGRAPHIC/OCEANOGRAPHY

Ocean floor mapping, Ship Safety and Navigation, Ocean Preservation

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