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Global navigation satellites system (GNSS): A guide for geomatics professionals and other GNSS operators

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Abstract

Throughout the course of time, our livelihood has been directly impacted by a series of innovative creations and discoveries made by mankind. The Satellites Navigation System (SATNAV) as a whole and Global Navigation Satellites System (GNSS) in particular, are part of those innovative creations which became indispensable to us.

From providing accurate navigation and transportation solutions to enhancing the monetary system with the use of advanced financial transaction systems, GNSS became an important tool in our society.
GNSS made it easy for professionals such as Geomatics Professionals to complete tasks in a record time whilst producing very accurate results; hence, it is the topic of this article.

This article explores the Global Navigation Satellites System (GNSS) by:

- Providing a detailed explanation on the fundamentals of GNSS,
- Highlighting the use of GNSS and some of its applications,
- Providing historical background and highlighting particularities of each of the four existing GNSS.
- Examining major GNSS methods of measurements used in Geomatics and related fields.
- Emphasizing the importance of understanding the process of Geo-positioning using GNSS operating devices.

Adding to the above-mentioned elements, this article emphasizes the role of the GNSS device operators, in being knowledgeable of the level of precision and accuracy required for any specific task that they deal with.

Keywords: Global Navigation Satellites System (GNSS); Satellites; Global Positioning System (GPS); Geo-Positioning; Navigation

1. Introduction

The aim of this article is to simply explain the basic operating process of some satellite navigation devices and more specifically, the renowned Geomatics GNSS (Global Navigation Satellites System) Base and Receiver systems.

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This article will lean on Geomatics to extract the necessary knowledge which will feed our minds with just enough to understand what GNSS (Global Navigation Satellites System) is, what GPS (Global Positioning System) is, what BDS (Beidou Navigation Satellites System) is, what GLONASS (Globalnaya Navigatsionnaya Sputnikovaya Sistema) is, what GALILEO is, what RTK is. And more importantly, we will know the "WHY?".

Why do we need all those amazing Technology systems in Today's World?

Well, let's begin with the starting point of this article: Surveying!

Charles D. Ghilani and paul R. Wolf, defined surveying as follow:

"Surveying, which has recently also been 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 which 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." Extracted from page 1**- *1. Introduction,1.1 Definition of Surveying*** of the book:
CHARLES D. GHILANI (The Pennsylvania State University) and PAUL R. WOLF (Professor Emeritus, Civil and Environmental Engineering University of Wisconsin–Madison) (22 September 2011), "Elementary Surveying, An Introduction to Geomatics", **Pearson Education; 13th edition.**

Surveying (Geomatics) is a science, and a mix of skills used to collect geospatial data for the sake of defining, monitoring or relocating man-made and natural features. All data collected relatively to an adopted datum. And such data are used for various land matters, geopolitical matters and matters related to precise measurements. Even some sport events make use of Land Surveying skills (the like of distance measurements and fitness tracking devices during sport events. i.e. The Olympics 2020 under COVID)

Geomatics is among fields where the Global Navigation Satellites System (GNSS) is used a lot.
From defining boundaries of Properties to Monitoring survey tasks, GNSS technology combined with appropriate skills channeled by mathematically and scientifically proven laws, assist Geomatics Professionals and other Professionals to complete tasks with a high level of accuracy and precision, which were once unachievable.

There are various Techniques and methods of approach used to define the position and elevation of features on Earth. As for the right method or Technique, it is subjective to the requirement of the specific task to complete. In other words, some Techniques will produce a much more precise and accurate result than others. So, it is up to the device operator to opt for the best Technique based on the criteria of the project and the result expected. Therefore, it is very important to gather the right set of tools and equipment which will assist in delivering the best result.

Nowadays, we are flooded with High-Tech equipment designed to work in various conditions but still produce results to less than a centimetre accuracy which makes it easier for today's professionals to deliver quality services in a short period of time.
Leveling Machines, Total Stations, GNSS devices (Base and Rover), Laser Scanner, Drones, etc. Just to mention a few gadgets used for positioning or monitoring of features on Earth.

The matter of interest in this article is the GNSS operating devices used to perform Geomatics Tasks.
It is essential to have a certain understanding of the process through which the accurate geo-positioning data are obtained using a GNSS Base and GNSS Receiver systems.

All existing GNSS (Global Navigation Satellites System): from the American GPS (Global Positioning System) to the Russian GLONASS (Globalnaya Navigatsionnaya Sputnikovaya Sistema), to the Chinese BDS (Beidou Navigation Satellites System) and the European Galileo, they all offer a wide range of services in their own styles and have the right to keep some services private. But due to spatial agreements and Laws governing the Global Navigation System, they exchange information and share certain data to maintain a Global Spatial harmony. Although GNSS is used in classified military operations, Nations and organizations managing these systems have established platforms for Global discussions, information sharing and common rules.

Regardless of the GNSS one chooses to work with, you will be able to achieve at least the following: Positioning, Navigating and Tracking.

- Positioning: Latitude in relation to the Equator, the Longitude relative to Greenwich Meridian (0 Longitude) and Elevation relative to the Mean Sea Level (MSL). It is commonly described as “Absolute Position”.
- Navigating: Moving from A to B
- Tracking: Locating A from B. Geomatics Professionals can recall the function “Stake Out” from their GNSS Controller.

The above GNSS functionalities are extracted from the article: ***Advanced Navigation (8 March 2023), “Global Navigation Satellite System (GNSS)and Satellite Navigation Explained”,***
https://www.advancednavigation.com/ ,https://www.advancednavigation.com/tech-articles/global-navigation-satellite-system-gnss-and-satellite-navigation-explained/#:~:text=By%20maintaining%20that%20synchronization%2C%20the,telecommunications%20companies%20and%20electricity%20suppliers , accessed on 2 November 2024.

2. What is Global Navigation Satellites System (GNSS)?

Global Navigation Satellites System is a term describing a constellation of satellites orbiting around Earth with the aim of providing highly accurate longitudinal data, latitudinal data, altitudinal data, velocity and time data (Time Signals). And all that mixture of data is broadcasted through a transmission path (mostly referred to as Line of sight) from the satellites to the receiving GNSS device.

GNSS is a type of Satellite Navigation System which covers the entire Globe, hence the wording “Global” Navigation Satellite System. There are other Satellites Navigation Systems (SatNav), referred to as “regional”.
Some of the Regional Navigation Satellites Systems (RNSS) are: Indian Regional Navigation Satellites System (IRNSS), the Japanese Quazi-Zenith Satellite System (QZSS), European Geostationary Navigation Overlay Service (EGNOS), just to mention a few.

GNSS works 24 hours, performs under all weather conditions and covers pretty much the entire Earth.
As it stands, scientifically, it requires at least 24 satellites for a Worldwide coverage Navigation system.

During data exchange between the satellites and the GNSS receivers, GNSS receivers require information about the satellites they are connected to.
Information such as:

- Accuracy of the clock, satellites age, health, etc. that package of data is known as “Ephemeris”.
- Orbital Parameters of satellites of the same system (Constellation) connected to the receiver. That type of data is often referred to as “Almanac Data”
- Clock corrections
- And other coding data

2.1. Why 24 satellites?

For GNSS to work, it takes at least 4 satellites, detectable or visible to the users at any part of the World. To achieve that, all the existing navigation satellites system providers dispatch their satellites constellation in multiple orbital planes. The sequence of satellites orbiting Earth is so precise that each satellite orbits 2 times a day (It is yet to be confirmed but GLONASS satellites operate in a different way than others).

Thus, in many GNSS devices (Receivers), a fixed position can be obtained with 4 to 5 satellites, given that the device is located away from any major signal obstruction.

With 4 satellites from the same Satellites Navigation System (SatNav), the fix is not super accurate but good enough to activate some functionalities and provide temporary data such as PVT (Position, Velocity, Time).
It has been proven that for a GNSS receiver to get a fix, it requires at least 4 satellites from the same system. And for a Satellites Navigation System (SatNav) to reach that status, it needs to have at least 24 active satellites orbiting Earth.

Russia by its territorial size and advanced technology is a good example of why 24 satellites is the minimum in this era. In 2011, with 21 satellites, Russia only managed the full coverage of its own territory.

2.2. GNSS Applications:

Some of the GNSS applications are:

- Navigation
- Defense
- Location
- Telecommunication
- Surveying
- Marine and Submarine
- Disaster Management
- Transportation
- Agriculture

2.3. Types of GNSS:

There are 4 major Global Navigation Satellite Systems:

2.2.1. Global Positioning System (GPS)
2.2.2. Globalnaya Navigatsionnaya Sputnikovaya Sistema (GLONASS)
2.2.3. BeiDou Navigation System (BDS)
2.2.4. Galileo

2.3.1. Global Positioning System (GPS):

This is an American satellite-based navigation system developed by the U.s Department of Defense. It was initiated in 1973 as a “joint Civil/Military Technical program”.
It operates with over 31 satellites orbiting the Earth at an altitude of approximately 11000 miles (17702.784 Km), according to the Federal Aviation Administration of the Department of Transportation of the United State of America. Attached below is the link to the article:

Federal Aviation Administration-Navigation Programs, “Satellite Navigation- Global Positioning System (GPS)”, https://www.faa.gov/,https://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/techops/navservices/gnss/gps#:~:text=Currently%2031%20GPS%20satellites%20orbit,Department%20of%20Defense%20(DoD), accessed on23 November 2024.

GPS is the first Global Navigation System invented. It is also the first one to be made available for civilian usage (some services, not all). But it is to be noted that GPS was mostly created for Military usage.
It has an orbital inclination of 55 degrees to the Equator, with a nearly circular orbit course.

The open to all sections of the GPS is part of what is known as the **user segment of GPS** (Includes both Military and non-Military users).

The other Segments of GPS are:

- For monitoring GPS operations and Ground stations located in various parts of the World. This segment is mostly referred to as “**the control segment of GPS**”,
- For Satellites constellation, referred to as the “**space segment”**
- Supervision and tracking of GPS satellites: **“Command centre (command segment).”**

The actual constellation of GPS satellites is spread in 6 orbital planes, with each satellite completing two Geocentric Orbits around planet Earth a day (Geocentric Orbit is a full rotation of a satellite or Astral element such as Moon around planet Earth).

GPS Datum is based on World Geodetic System 1984 (WGS84), with the Earth shape being assumed Ellipsoidal.

2.3.2. Globalnaya Navigatsionnaya Sputnikovaya Sistema (GLONASS):

GLONASS, with its English translation being **Global Navigation Satellite System**, is a Russia satellite-based navigation system managed by the Russian Armed Forces.

It is believed to be the continuity of the Satellite Navigation System developed under the Soviet Union.

The development of GLONASS started in the early 1980s, the full constellation is believed to be reached in the mid-90s and in 2011 an advanced version of GLONASS known as GLONASS-K was fully developed with the potential to fully provide Global services at the same level as the American GPS.
GLONASS has 31 satellites spread in three orbital planes, inclined at 64.8 degrees at about 19100Km (Debatable) of altitude above the Earth surface.

Although GPS is overall consistent with better coverage Worldwide, GLONASS is a much better performing Navigation system in the North and South Pole due to the 64.8-degree orbital inclination of its satellites to the Equator.

The above statement is nicely described in the following sample of the P.h.D Thesis of ***João Paulo Ramalho Marreiros (December 2012), "Kinematic GNSS Precise Point Positioning", P.h.D Thesis in Surveying Engineering, Faculty of Science, University of Porto.***

Quoted as follows, in ***Annex A, Page122-Section A.3.1 Space segment and signals***,**2nd Paragraph**:

"A characteristic of the GLONASS constellation is that any given satellite only passes over the exact same spot over the Earth every eighth sidereal day. The system is designed in such a way that constellations, and therefore DOP-values will repeat each sidereal day, but with different satellites. For comparison each GPS satellite passes over the same spot twice every sidereal day. Also, users in higher latitude areas obtain better GLONASS DOP-values than GPS, due to the higher inclination of satellite orbits."

The actual constellation of GLONASS satellites is spread in 3 orbital planes, with each satellite completing 17 revolutions in 8 sidereal days to revisit the same spot.
Note a sidereal day is approximately 86,164 seconds or 23h 56min 4.0905 seconds or 23.9344696 h.

GLONASS datum is based on Parametry Zemli 1990.11 (PZ-90.11), with the Earth shape being Ellipsoidal.

2.3.3. Beidou Navigation Satellite System (BDS):

The word "Beidou" translated to "Northern Dipper" or "Big Dipper" or "Plough", according to translations of various Encyclopedias.
"Big Dipper" is a constellation of Seven Stars, believed to be visibly the brightest in the shape of a "Handle and a Bowl/Big Spoon" mostly visible in the Northern Horizon in Spring Nights. They are not visible in regions with Latitude higher than 29 degrees, making it more likely a Northern Hemisphere thing.

Beidou Navigation Satellite System is a Chinese made Satellite-based navigation System. It is the third Global Navigation Satellite System to be operational after the American GPS and the Russian GLONASS.

Developed by the Chinese National Space Agency (CNSA), BDS started off as a regional navigation system with its early version known as BEIDOU-1 in the 90s. With the need for more coverage and the ambition to reach the status of a Global Navigation Satellite System, China upgraded the technology of BEIDOU-1 to create BEIDOU-2 and eventually developed a more powerful Navigation System known BEIDOU-3 which is currently in use and covers the global needs at the same status as the other 3 GNSS. BEIDOU has reached the criteria for Global coverage with a full satellite constellation in 2020.

In total, 30 actives Beidou Satellites are orbiting the Earth, according to the article "BeiDou Navigation Satellite System Signal in Space Interface Control Document Search and Rescue Service (Version 1.0)" published in 2020, by China Satellite Navigation Office, attached in the following link:

http://en.beidou.gov.cn/SYSTEMS/ICD/202008/P020200803535920317313.pdf , accessed on the 30th of November 2024.

Quoted below is a detailed description of satellites constellation of Beidou, found in Section 3.1 Space Constellation of the above article:

"The nominal space constellation of BDS-3 consists of 3 Geostationary Earth Orbit (GEO) satellites, 3 IGSO satellites, and 24 MEO satellites. According to the actual situation, spare satellites may be deployed in orbit. The GEO satellites operate in orbit at an altitude of 35,786 kilometers and are located at 80°E, 110.5°E, and 140°E respectively. The IGSO satellites operate in orbit at an altitude of 35,786 kilometers and an inclination of the orbital planes of 55 degrees with reference to the equatorial plane. The MEO satellites operate in orbit at an altitude of 21,528 kilometers and an inclination of the orbital planes of 55 degrees with reference to the equatorial plane."

BeiDou Navigation Satellites System (BDS) ground stations comprise:

- Master control stations,
- Time synchronization/Uplink stations,
- Monitoring stations,
- Operation and management facilities of the inter-satellite link.

BeiDou Navigation Satellites System ground Stations, extracted from the website: ***Beidou Navigation Satellite System, "System",***
http://en.beidou.gov.cn/SYSTEMS/System/#:~:text=The%20BDS%20ground%20segment%20consists,of%20the%20inter%2Dsatellite%20link , accessed on 1 December 2024.

Note that BDS is based on the Chinese Geodetic Coordinates System 2000 (CGCS2000), it is accordance with ITRS (International Terrestrial Reference System). The Earth shape is assumed to be Ellipsoidal.

2.3.4. Galileo

This is a Global Navigation Satellites System owned by the European Union. Unlike other Navigation Satellites System, Galileo was created by civilians, and it is fully managed by the European Union Agency for the Space Programme (EUSPA) which is a civilian organization. Although Galileo offers services for Police departments in Europe, it was created for Civilian usage.
Besides the experimental missions GIOVE-A and GIOVE-B, in 2005 and 2008. The structure of the Galileo Navigation Satellites System used Today, started in 2011.

Galileo satellites orbit in three circular medium planes at about 23222 Km of altitude. It has 28 active satellites, with an orbital inclination of 56 degrees to the Equator.
According to the European Commission Defense Industry and Space, in of their article "Galileo, the European Union Global Navigation Satellite System" published in April 2024:

Galileo satellites constellation is made of 24 satellites orbiting at about 23222 Km of altitude.
"Galileo is **three times more accurate** than GPS providing 1 meter accuracy and a broad range of services."

Around 10% of the EU economy depends on the availability of global navigation satellite signals.
Galileo services (Actuals):

- **Galileo Open Service (OS):** the most commonly used service we all rely on, in our phones, cars and smartwatches.
- **Galileo Search and Rescue (SAR):** allows the location of people in distress in less than 10 mins and accuracy error below 5km.
- **Galileo High Accuracy Service (HAS):** offering an accuracy down to 20cm for applications such as autonomous cars or drones.
- **Galileo Public Regulated Service (PRS):** for authorized users of EU Member States, such as defense, civil protection services, customs officers, police, etc. This system is particularly robust and fully encrypted to provide service continuity during emergencies or crisis situations.
- Coming soon
- **Galileo Open Service Navigation Authentication Message (OSNMA)**: A service which will secure Galileo signals against spoofing by enabling authentication of navigation data.
- **Galileo Emergency Warning Satellite Service (EWSS)**: a service which will complement national alert systems by transmitting alert messages via the Galileo satellites when other terrestrial means are unavailable (4/5G towers).

More explanatory details about Galileo Satellites are on the official website of the ***European Commission,EU-Space, "Galileo I Satellites Navigation",*** https://Defense-industry-space.ec.europa.eu/,https://Defense-industry-space.ec.europa.eu/eu-space/galileo-satellite-navigation_en , accessed on 1 December 2024.

Galileo is based on the Galileo Terrestrial Reference Frame (GTRF), with the Earth shape assumed to be Ellipsoidal.

Table 1 Difference between GPS, GLONASS and GALILEO Constellations

	GLONASS	**GPS**	**GALILEO**
Number of nominal satellites	24	24	30
Number of orbital planes	3	6	3
Orbital Inclination	64° 8’	55°	56°
Orbital altitude	19.140 km	20.180 km	23.222km
Period of revolution	11h 15m	11h 58m	14h 22m
Launch site	Baikonur/Plesetsk	Cape Canaveral	Kourou (French Guiana)
Date of first launch	02/10/82	22/02/78	N/A
Satellites for launch	1/3	1	2
Datum	PZ-90.11	WGS-84	GTRF

Table copied from: European Space Agency (15 August 2024), ***“GLONASS Satellite Constellation”,*** https://gssc.esa.int/, https://gssc.esa.int/navipedia/index.php/GLONASS_Space_Segment. Accessed on 30 December 2024.

3. Types of GNSS Surveying Methods of correction of Measurement

Considering the limitation due to time and size of the article, the adopted approach for this section of the article is mostly to provide general definition and methodology of the two main GNSS Surveying methods/techniques, and a listing of some subtypes associated with each method without excessive detailed analysis. A compilation of definitions, illustrations and links describing each subtype, will be attached for those willing to read furthermore.

There are several GNSS Surveying methods used to produce precise and accurate measurements. But many experts subdivide them into two groups:

- Kinematic Positioning methods (Real-Time Kinematic: RTK)
- Static Positioning methods.

A brilliant comparative explanation between the two methods is displayed in the ***RICS Professional standard (May 2023), “Use of GNSS in land surveying and mapping”, Global 3rd edition.*** It is quoted in ***section 3.2. Kinematic*** of the manual:

“Kinematic surveys provide the highest production rate for all the GNSS methods. While rapidly generating coordinates, the precision obtained is not as high as by static techniques. This is because in kinematic techniques, most random measurement and GNSS system errors are absorbed in the coordinates. This can be contrasted with static methods, in which they are absorbed in the residuals after a network adjustment.”

Therefore, both RTK and static are methods used for high precision tasks, but it all depends on the type of task, the result expected, the level of accuracy and precision required.

Bear in mind that the baseline (Difference in Position or Distance separating the GNSS receivers connected to a specific satellite system) has a huge influence on the quality of observations in both RTK and Static.

How long should the baseline be?

Well, there are a few factors to consider in this case such as the level of accuracy required, topology, quality of the GNSS equipment, weather conditions, just to name a few.

If the ratio of all factors which could possibly affect the signal is minor, then a longer baseline would do no harm but still, it is advised to keep the maximum baseline length within 10 to 20 km. But, in a situation where there is a possibility of obstruction of signal, then keeping the baseline a bit shorter will help produce better results.

3.1. Real-Time Kinematic Positioning Method:

3.1.1. Definition and Methodology

In simple words, RTK (Real-Time Kinematic) is a technique used to improve the quality of data collected during a GNSS data collection operation in real-time.

This GNSS method of correction of measurements is performed with at least one fixed base station and one mobile station, connected to the same satellites. It is very accurate and one of the most used methods.

GNSS (Global Navigation Satellites System) combined with RTK (Real-Time Kinematic), is one of the go-to techniques commonly used by Geomatics professionals and other professionals to define the position (Latitude, Longitude and Elevation) of elements or features on Earth. Those features can be Man-Made such as Buildings, Roads, Services etc or Natural Features such Trees, Streams, etc.

Ideally, it is much easier to have a bunch of known points/Controls/Benchmarks, from one of which you will set up your GNSS Base and use the other Points to check your setup before starting. But the reality is not always that simple.
More often, Professionals are faced with obstacles forcing them to set up the base on a random Position commonly known as "Here Point/Randon GNSS Point", then proceed to find few known points to calibrate (shift) the base position onto the found "known points" system. And of course, the GNSS device operator must make sure the found known points are displaying a consistent discrepancy and use their own judgement (Expertise) to properly apply the shift.

Some people prefer a single point calibration (Find one known point, compare the actual coordinate of the found point with the surveyed/measured coordinate, then apply that shift to your GNSS Base "Here Point"/ "Random Point" coordinate) of the GNSS base and then check onto more known points.

Others prefer to find a bunch of known points and apply a mean shift (Find 2 or more Known points with similar discrepancies, compare their actuals values to the measured values and finally apply the mean correction to all measured points).

Both procedures are proven to be correct and nowadays, it is done onboard of the GNSS device under a commonly known "Site Calibration".

A particular advantage of RTK is that it does not require an excessive amount of time and yet produce very accurate results. But remember, the right method is conditional on the type of task and the result to be achieved, therefore the knowledge of the GNSS operator is yet again called up to action.

3.2. Types of Real-Time Positioning Methods:

3.2.1. Differential Global Navigation Satellite System (DGNSS)

"Differential GNSS (DGNSS) is a kind of GNSS Augmentation system based on an enhancement to primary GNSS constellation(s) information using a network of ground-based reference stations which enable the broadcasting of differential information to the user to improve the accuracy of his position. Differential GNSS (DGNSS) system is a means of improving the accuracy of GNSS and providing integrity monitoring to the user. DGNSS involves having reference stations, at precisely known locations that provide real-time corrections and integrity information for GNSS signals. DGNSS systems provide shore-to-ship services."
Extract of the 2nd paragraph of the web page: ***Directorate General of Lighthouses and Lightships, Ministry of Ports, Shipping and Waterways, Government of India, Service Rendered-DGNSS, "DGNSS",*** https://www.dgll.nic.in/, https://www.dgll.nic.in/about-DGLL/Service-reminders/dgnss, Accessed on 2 December 2024.

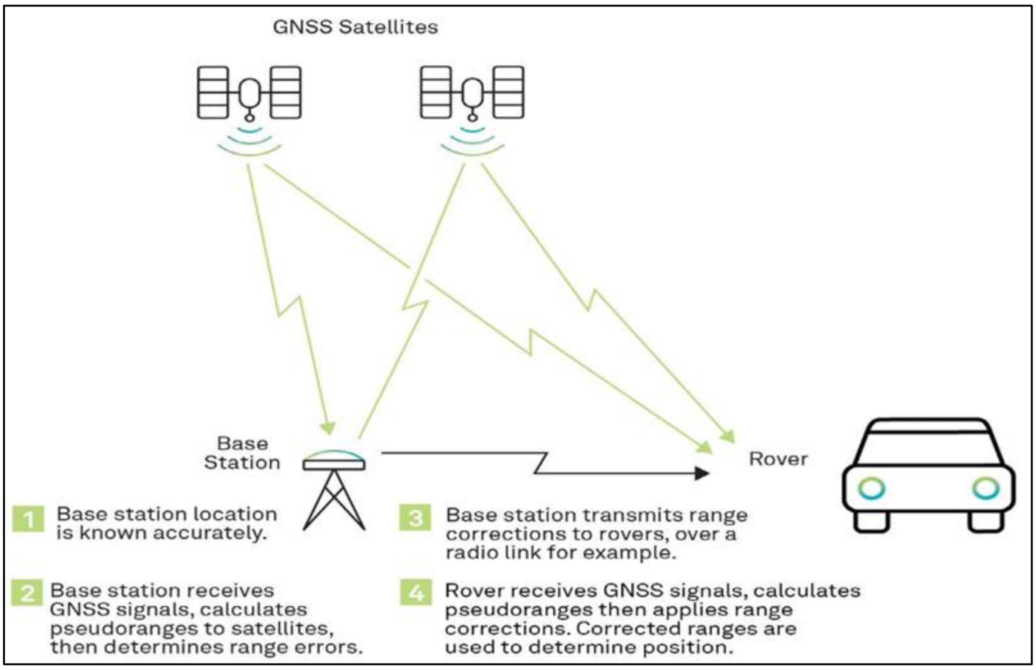

Image copied from Figure 41 Differential GNSS (DGNSS) Overview (Extracted from Chapter 5 Resolving Errors-Differential GNSS(DGNSS)) of the 3rd edition of the book: Industry Experts from Hexagon | NovAtel (28 March 2023), "An Introduction to GNSS. A primer in using Global Navigation Satellite Systems for positioning and autonomy." Published by Hexagon | NovAtel, https://novatel.com/, https://novatel.com/an-introduction-to-gnss/resolving-errors/differential-gnss, accessed on 1 December 2024.

Figure 1 Differential GNSS (DGNSS) Overview

3.2.2. Precise (Absolute) Point Positioning RTK (Real-Time Kinematic)

"Precise point positioning (PPP) stands out as an optimal approach for providing standalone static and kinematic geodetic point positioning solutions using all the available GNSS constellations. Combining precise satellite orbits and clocks with un-differenced, dual-frequency, pseudo-range and carrier-phase observables, PPP is able to provide position solutions at centimeter-level precision."

Extracted from the web page: ***European Space Agency (2011), "Precise Point Positioning"***, https://gssc.esa.int/ ,https://gssc.esa.int/navipedia/index.php/Precise_Point_Positioning , accessed on 30 December 2024.

"PPP is a positioning technique that removes or models GNSS errors to provide a high level of position accuracy from a single receiver. A PPP solution depends on a set of corrections generated from a network of global reference stations. Once the corrections are calculated, they are delivered to the end-user via satellite or over the Internet. These corrections are used by the receiver to improve position accuracy." Extracted from (Extracted from Chapter 5 Resolving Errors-Precise Point Positioning (PPP)) of the 3rd edition of the book: ***Industry Experts from Hexagon | NovAtel (28 March 2023), "An Introduction to GNSS. A primer in using Global Navigation Satellite Systems for positioning and autonomy."*** Published by ***Hexagon | NovAtel,*** https://novatel.com/ ,

https://novatel.com/an-introduction-to-gnss/resolving-errors/ppp, accessed on 1 December 2024.

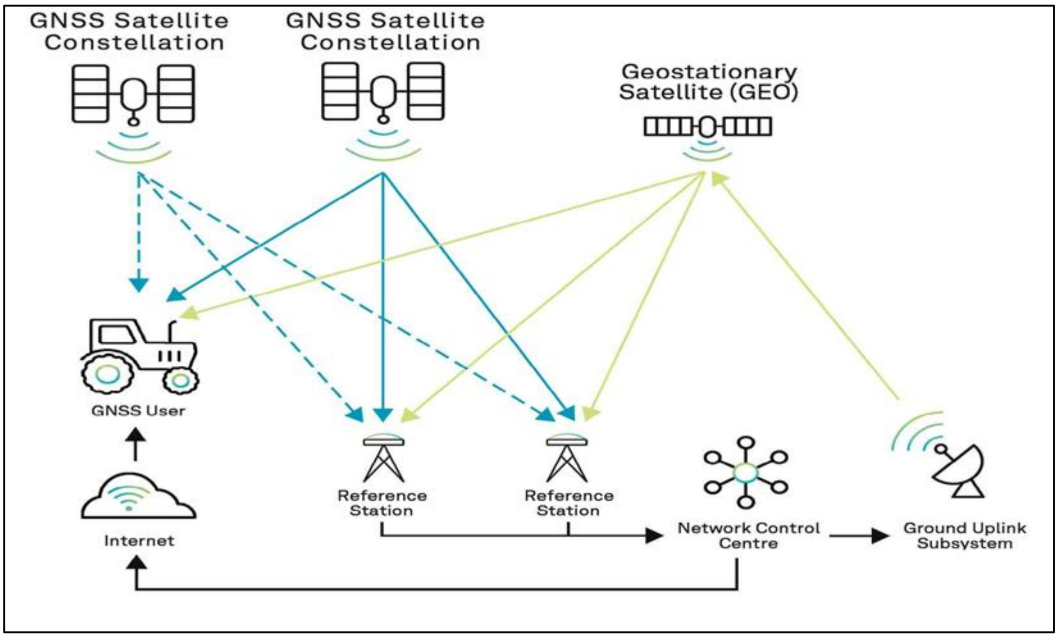

Image copied from ***Figure 44 Precise Point Positioning (PPP) system overview*** (Extracted from Chapter 5 Resolving Errors-Precise Point Positioning (PPP)) of the 3rd edition of the book: ***Industry Experts from Hexagon | NovAtel (28 March 2023), "An Introduction to GNSS. A primer in using Global Navigation Satellite Systems for positioning and autonomy."*** Published by ***Hexagon | NovAtel,*** https://novatel.com/ , https://novatel.com/an-introduction-to-gnss/resolving-errors/ppp , accessed on 1 December 2024.

Figure 2 Precise Point Positioning (PPP) system overview

3.3. Static Positioning methods

3.3.1. Definition and Methodology

Static Positioning is a high accuracy GNSS "survey" technique used to define geo-spatial data of a point or feature. Unlike RTK, Static Positioning requires a longer station setup time. The longer the occupation time, the higher the accuracy and the better the result. Depending on the result required and the task or job type, the setup time and detail are variable.

A traditional Static (method) set of equipment revolves around a base receiver connected to one or more rover receivers via radio link signals. Static setup demands a bit more attention than a traditional RTK. Since the occupation time is longer, the operator must fix the equipment in such a way that it will stay stable and undisturbed throughout the station occupational time. Both the base receiver and the rover receiver record on their own the satellites observations. Once the operator is satisfied/ completed the task, the GNSS operation can be shut down, and the stored observations are extracted by one of the various post-processing procedures in the office.

If you don't have the time or the patience, then don't use static.

3.3.2. Types of Static Positioning Methods:

Rapid Static

"The rapid static method is still an attractive method of surveying with GPS. It combines high accuracy and short observation periods, being useful in applications when redundancy of observations is desired, such as in legal surveys." Extracted from the abstract of the article: ***Marcelo Santos, C.B.Souza and Silvia De Freitas (January 2000)***,

"***A practical evaluation of the GPS rapid static method"***,

https://www.researchgate.net/publication/283598410_A_practical_evaluation_of_the_GPS_rapid_static_method, accessed on 13 December 2024

"…The rapid static method is similar to high-precision static surveys, but occupation times are reduced, depending on conditions. The key technical differences between high-precision static and rapid are:

- The processing software should have sophisticated processing algorithms to allow computation of the baselines.
- It is of greater importance that the survey data should be virtually free of cycle slips, multipath and interference.
- Good satellite geometry is critical.
- Baselines are limited to a maximum of 40km.

These more onerous conditions are all required, even though rapid static gives only a medium precision outcome, because a smaller amount of data is used to estimate and obtain the correct baseline solution. ” Extracted from section . Kinematic of RICS Professional standard (May 2023), “Use of GNSS in land surveying and mapping”, Global 3rd edition. Accessed on 13 December 2024.

Static Baseline

“Dual-frequency static methods (for baselines of less than 100km) are most suitable for control surveys and afford the highest precision (sub-cm) achievable with GNSS. They require the simultaneous observation at two or more stations of GNSS data from four or more common satellites.” Extracted from section 3.1.1 Static Baseline of RICS Professional standard (May 2023), “Use of GNSS in land surveying and mapping”, Global 3rd edition. Accessed on 13 December 2024.

Static Network RTK

“With network RTK, instead of using a base station set up over a known point collecting simultaneous observations, the user subscribes to a network RTK correction service that provides the base station data.” Extracted from section **3.1.3 Static Network RTK** of ***RICS Professional standard (May 2023), “Use of GNSS in land surveying and mapping”, Global 3rd edition.*** Accessed on 13 December 2024.

3.4. NTRIP-Network Transport of RTCM (Radio Technical Commission for Maritime Services) via Internet Protocol

This article does not classify NTRIP as part of RTK (Real-Time Kinematic) nor does it attribute an autonomous status to NTRIP, but instead it does highlight the difference in connectivity between the receivers and the satellites compared to the traditional RTK (Real-Time Kinematic) techniques and Static Techniques, which use radio links in place of internet connection.

NTRIP is more likely a sort of RTK (Real-Time Kinematic) technique, in which data exchange is executed via the internet instead of radio link. For that reason, many experts do classify it as one of the RTK (Real-Time Kinematic) techniques.

NTRIP as the meaning of “P” says it, is a protocol or procedure of data exchange or data transfer between a Satellite Navigation System (SatNav) or Global Navigation Satellite System (GNSS), ground-based receiver and mobile receivers (SatNav/GNSS receivers) by means of the Internet connection.

The basic conditions of working with NTRIP are:

- GNSS Rover and controller set in good working condition.
- Good internet connection, either using Mobile Data (with a Sim card on board) or Wi-Fi connection or you can use an external Router such as your Cell phone to Hotspot the GNSS device.
- Established Bluetooth connection between GNSS rover and Controller.
- The availability of active Ground Stations, usually a list of nearby stations will be appear in the controller, and from which you will be able to select a suitable station.

On average, NTRIP does not need excessive amount of data to operate. A full day survey job can be completed with a significantly small amount of data, but this depending on the Tariffs of the Network provider one uses and on the Country. In South Africa for example, a full day NTRIP survey consumes on average way less than a Gigabyte using most of the major Network providers Sim card.

3.4. Why do many professionals confuse GNSS with GPS?

More often, when GNSS Operators such as Geomatics Professionals are asked by normal citizens about the name and the use of the GNSS devices they are operating; in most scenarios, their go-to phrase is usually “This is a GPS” and then, they go on explaining that it works with satellites to determine the position of whatever elements they are about to measure. And when explaining the “How it works”, many intend to mention “Triangulation” as the method used by satellites to fix points. Those who witnessed or went through that explanatory process, know that “Triangulation explanation" is often accompanied with some confusing finger pointing movements to emphasize the Base-Rover-Sky (referring to Satellites) relation or data travelling trajectory.

Firstly, if the "GPS" label given to a GNSS device is used as a "Keyword" because (nowadays) everyone has an idea of what GPS is or at least heard of it with the hailing App (on demand App services), then, it is a good technique as long as it is only a way to give a rough idea to the one asking. But **let it be known that all GNSS devices do not necessarily use "GPS" technology.** Places such as Europe (a big part of it), Russia, the Pole Regions or China, use other Global Navigation Satellite Systems (GNSS) instead of GPS.

Secondly, Triangulation is most likely not the method used to define absolute positions from SATNAV/GNSS because it requires defined angles. It is known that GNSS with their satellite constellation operate with Time signals from the synchronized atomic clocks of satellites, rather than angles. Therefore, the right method used is rather "**Trilateration**" because it works with distances, not angles.

3.5. GNSS Trilateration Method /Process

The GNSS base and rover connect to the same satellites. The GNSS satellites send coded signals in an exact sequence to the GNSS receiver via the receiver antenna, the receiver then computes a travelling time estimation to define the correction, which is also transferred to the rover or other receiver in case of multiple stations. And with the use of the speed of light, an accurate distance from satellites to the connected GNSS Base and GNSS Rover can be obtained.

Note that various corrections are applied to the GNSS observations, such as Clock Offsets, Time delay, Atmospheric errors, etc.

Remember, **Galileo defined speed as the distance covered per unit of time**.

In other words, he said: **Distance=Time X Speed**.

So, the same principle is applied here, where the speed of light and travelling time of satellite signals are the known data used to compute the distance between each satellite and the GNSS receivers.

Here below are some general thoughts, which could simplify the difference between GNSS-GPS and the concept of GNSS trilateration for the Geo-Spatial Position of element of Earth:

3.5.1. Think of GNSS this way:

In a non-professional way, think of GNSS as cell phones in general and GPS being a specific American made cell phone brand with a specific operating system.

It has some similar functionalities with the Chinese made Cell phone (being BDS), or European made Cell phone (Being Galileo) or the Russian made (being GLONASS) but they also have differences, yet they are all part of cell phones family (which in this case refers to GNSS in general).

3.5.2. Simplified Geo-spatial positioning concept:

As human beings, you can create a pretty consistent sequence of time to match each of your steps. By using a watch, you can roughly estimate the time of each of your steps. Once the time is known, one can then estimate the stretch/length per step and the velocity/Speed. Distance being the element to solve, having the two known data (estimated time per Step length and estimated Velocity/Speed), one can apply Galileo's law of Speed to find the Total distance covered from the starting location "A" to the final location "B".

Similar concept is used in GNSS, but instead of a normal watch/Clock device, some kind of "super Clocks" known as "Atomic Clocks" are used to produce the highest level of accurate Time data transmitted in a precise sequence. Most modern satellites are reported to carry 4 atomic Clocks. Some experts (The likes of the cyber security and IT expert Bert Hubert) are even stating that 4 is not enough.

The concept is similar, but the collection and delivery of data is via super advanced tools and super accurate scientific methods.

Therefore, when asked: How does the GNSS fix the position of point? the answer is by "**Trilateration**".

GNSS Devices use the accurate time signal from at least 4 satellites, calculate the Distance to the GNSS receiver, and define the absolute position of features.

Trilateration being the method used to define the geo-spatial position in GNSS, is a statement supported by many Spatial experts, the likes of Dr Robert Thirsk a retired Canadian Engineer, Physician and Former Astronaut of the Canadian Space Agency (He is the holder of the Canadian record of the most time spent in space by a Canadian citizen). He participated and wrote a foreword for the 3rd Edition of the book titled:

"An Introduction to GNSS. A primer in using Global Navigation Satellite Systems for positioning and autonomy." Written by industry experts from Hexagon NovAtel (28 March 2023) and published by Hexagon NovAtel.

It is quoted in "*Step4-Computation"* of *"Chapter 2 Basic GNSS Concepts"* of the book:

"For each satellite being tracked, the receiver now knows where the satellite was at the time of transmission (because the satellite broadcasts its orbit ephemerides) and it has determined the distance to the satellite when it was there. Using trilateration, a method of geometrically determining the position of an object in a manner similar to triangulation, the receiver calculates its position." The above-mentioned quote proves clearly that Trilateration is indeed the adopted method for Geo-Positioning for GNSS operations.

As for why the GNSS is commonly confused for GPS, it is hard to narrow down that misunderstanding to a particular reason.
Maybe it is because of the seniority of GPS, maybe because users trust it more or maybe the Americans advertised it well, or because many people are just not aware of the existence of other GNSS. There are plenty of factors around that debate, but hopefully this article added a wave of knowledge to the readers.

4. Conclusion

The four major Global Navigation Satellite Systems, together with other existing Satellites Navigation Systems, reshaped our lives positively. The Satellites Navigation System still requires more explorations for mankind to fully benefit from it.

It is in our duties as Geoscience experts together with other scientists to accustom the world to this amazing piece of technology and ensure the right usage for an improved livelihood in our society.

May this article provide a decent understanding of the Global Navigation Satellite System and motivate others to continue the path of exploring this wonderful side of Geoscience.

Compliance with ethical standards

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