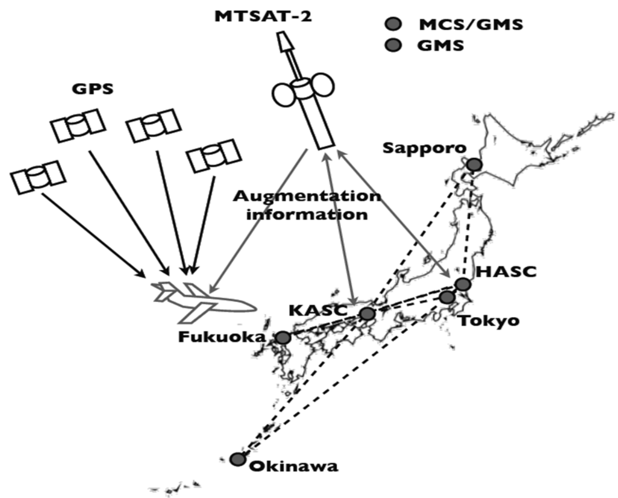

Figure 3.27 Concept of MSAS survey (Source: https://www.icao.int/APAC/APAC-RSO/GBASSBAS%20 Implementation%20Workshop/1-6_MSAS%20System%20Development_Rev2%20(S%20Saito).pdf)

3. EGNOS, Europe:

The European Geostationary Navigation Overlay Service (EGNOS) is Europe's SBAS that is used to improve the performance of GNSSs, such as GPS and Galileo. It will be used to provide the safety of life navigation services to aviation, maritime and land-based users over most of Europe (https://www.euspa.europa.eu/european-space/egnos/what-egnos). The EGNOS augments the GNSS L1 Coarse/ Acquisition (C/A) civilian signal by providing corrections and integrity information for space vehicles (ephemeris, clock errors) and most importantly, information to estimate the ionosphere delays affecting the observations (https://egnos-user-support.essp-sas.eu/new_egnos_ops/egnos-system/about-egnos).

The EGNOS uses GNSS measurements taken by accurately located reference stations installed across Europe. All measured GNSS errors are transferred to a central computing centre, where differential corrections and integrity messages are calculated, and results broadcasted over the covered area using geostationary satellites that serve as an augmentation to the original GNSS message. As a result, the EGNOS improves the accuracy and reliability of GNSS positioning, while also providing a crucial integrity message regarding the continuity and availability of a signal. In addition, the EGNOS also transmits an extremely accurate universal time signal. The services will be progressively extended to the European neighbourhood countries.

4. GAGAN, India:

The GAGAN (GPS Aided GEO Augmented Navigation) is a SBAS, jointly developed by ISRO and AAI to provide the best possible navigational services over Indian FIR (Flight Information Region) with the capability of expanding to neighbouring FIRs. It has is a system of geostationary satellites and ground stations that provide signal corrections to give better position accuracy for several services, such as aviation, forest management, railways signalling, scientific research for atmospheric studies, natural resource and land management, Location based services, Mobile, Tourism. The GAGAN corrects for GPS signal errors caused by ionospheric disturbances, timing and satellite orbit errors and also it provides vital information regarding the health of each satellite (https://gagan.aai.aero/gagan/).

The GAGAN consists of set of ground reference stations positioned across India, called Indian Reference Station (INRES), which collect GNSS satellite data. A master station collects the data from reference stations and creates GNSS correction messages. The corrected differential messages are broadcasted on a signal from three geostationary satellites (GSAT-8, GSAT-10 and GSAT-15). The information on this signal is compatible with basic GPS signal structure, which means any SBAS enabled GNSS receiver can read this signal (https://www.asimindia.in/what-is-gagan-waas/). The system is interoperable with other international SBAS systems, such as the WAAS, EGNOS), and MSAS, and provides seamless air navigation across regional boundaries.

5. SDCM, Russia:
The System for Differential Corrections and Monitoring (SDCM) is the SBAS currently being developed by the JSC (Russian Space Systems), as a component of GLONASS (https://gssc.esa.int/navipedia/index.php/SDCM). The main differentiator of SDCM with respect to other SBAS systems is that it is conceived as an SBAS augmentation that would perform integrity monitoring of both GPS and GLONASS satellites, for providing high accuracy solutions, updated and reliable integrity data. The SDCM is expected to provide horizontal accuracy of 1.0-1.5 m and vertical accuracy of 2.0-3.0 m (https://www.unoosa.org/documents/pdf/icg/activities/2008/expert/2-5b.pdf).

The GLONASS and GPS system signals measurement data from measurement data collection stations is transferred to system processing center, where associated correction data and navigational field integrity data are generated, and which are delivered to users via geosynchronous communications satellites or via ground communication channels. User's receiver performs overlapped processing of this data and GLONASS and GPS system signals, which allows solving navigational tasks with improved precision and reliability characteristics.

3.4.10 Accuracy of GNSS observations
The GPS is a pervasive and wonderful technology. It is the first positioning system to offer very high accuracy in most surveying and navigational applications at low-cost and with high efficiency. There are different levels of accuracy that can be achieved using appropriate receiver and technique. There are two main factors that determine the accuracy of a GNSS position (Garg, 2021): (i) error on range measurement (Noise+Systematic), and (ii) geometry of the satellites. The first factor has many components that are controlled by the receiver and the local environment of the system. The second factor is not under the control of the user, except by using a receiver with large channels. Accuracies routinely achieved in measurement of baseline lengths in relative mode, using high precision geodetic instrumentation, with many hours of observations and scientific data processing, are as follows:

(i) 0.1-4 mm in local surveys (10 m-100 km baseline lengths)
(ii) 4-10 mm in regional surveys (100-1000 km baseline lengths), and
(iii) 1-2 cm in global surveys (1000-10000 km baseline lengths)

Most GPS units in standalone mode may have an accuracy of about ±10 m. The DGNSS technique further improves that accuracy better than ±1 m by adding ground-based reference station. For standalone users, the extent use of phase is a major factor in achieving the accuracy. The noise on the phase is typically 1 mm to provide the range 10 cm to 1 m. Therefore, the use of phase data in a way can improve the accuracy. The multipath also significantly reduces the phase measurement. In point positioning mode, accuracy within meter with 1 epoch solution and 24 hours of observations may be possible (depends on Selective Availability). In Differential mode, accuracy in cm (in P Code) and 1-5 m (in CA code) may be obtained, while accuracy of 5 mm ± 1 ppm may be obtained on Differential phase mode. Special techniques (called Kinematics) make use of the phase to achieve higher accuracies. However, they are normally used to range 25 to 50 km baselines. On May 1 2000, the US government made the SA available to all civil and commercial users world-wide (Garg, 2019).

Figure 3.28 presents the accuracy of some available GPS systems. The vertical axis is the expected accuracy or error level, while the horizontal axis is the distance along the Earth's surface between the reference station and the user. If there is no reference station, the line is drawn all the way to 10,000 km, all over the Earth.

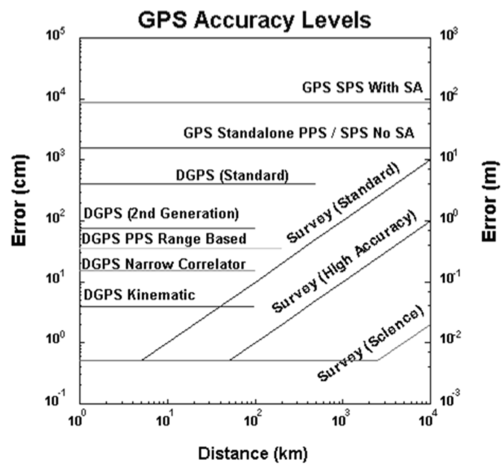

Figure 3.28 Various accuracy levels using GPS (Source: https://www.oc.nps.edu/oc2902w/gps/gpsacc.html)

3.4.11 Errors in GNSS observations

The process of transmitting, receiving and detecting the GNSS signals may contain certain errors. The GNSS positioning accuracy is affected due to (Garg, 2021): (i) satellite signal blockage owing to high-rise buildings, bridges, dense forest trees, etc., (ii) indoor or underground use of GNSS, and (iii) signals reflected-off buildings or walls ("multipath"). Other causes may include: (i) radio interference or jamming, (ii) major solar storms, (iii) satellite maintenance/ manoeuvres creating temporary gaps in coverage, and (iv) improperly designed devices that do not comply with GNSS interface specifications. Due to mapping software, the errors may include, such as, (i) incorrectly drawn maps, (ii) mislabelled businesses and other points of interest, and (iii) missing features, etc. The major sources of errors and their magnitudes are given in Table 3.8. These are shown in Figure 3.29, and explained below-

Table 3.8 The GPS error budget (at 1σ value) (Rathore, 2017)

Error type	**Error (m)**	**Segment**
Ephemeris	3.0	Signal-in-space
Clock	3.0	Signal-in-space
Ionosphere	4.0	Atmosphere
Troposphere	0.7	Atmosphere
Multipath	1.4	Receiver
Receiver	0.8	Receiver

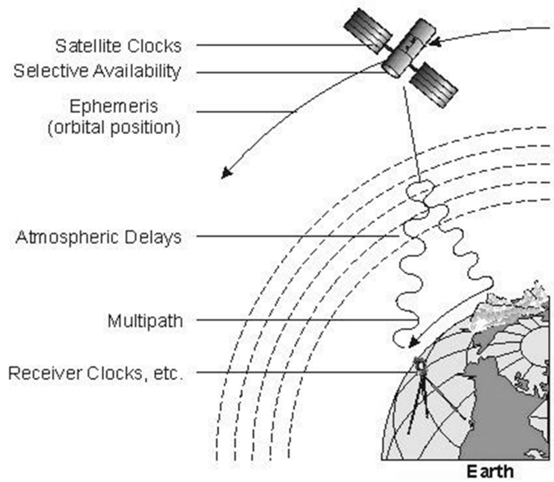

Figure 3.29 Various sources of errors (Source: https://www.ocean-yachting.com/gps-error-sources)

1. *Receiver clock errors*- A receiver's built-in clock is not so accurate as the atomic clocks on-board GPS satellites, therefore, the data may have slight timing errors.
2. *Orbital errors*- These are also known as *ephemeris errors* that are the inaccuracies in the reported locations of satellites.
3. *Number of satellites visible*- In general, lesser the number of satellites tracked, lesser is the accuracy of GNSS observations.
4. *Interferences*- Magnetic terrain, magnetic ores, electronic interferences, electric poles, etc., can cause positional errors in measurements.
5. *Undercover*- Typical GNSS units do not work indoors, underwater or underground.
6. *Multi-path error*- It occurs when the GNSS signals are reflected-off the objects falling in the path, such as tall buildings or dense forest or large mountain, before it reaches the GNSS receiver (Figure 3.30). This is called multi-path error as the signal is reaching the antenna in single line path as well as delayed path. This deviates the signal from its original path and increases the travel time of the signal, thereby causing few meters of errors.

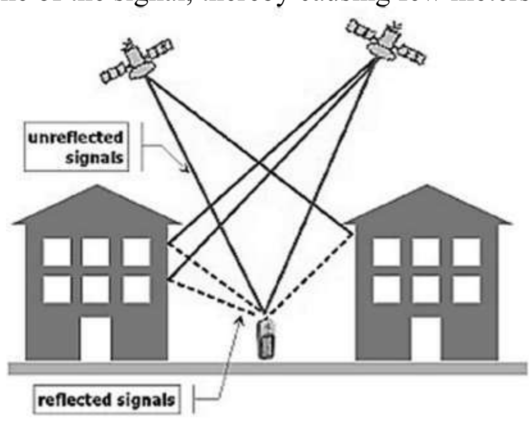

Figure 3.30 Depiction of multipath error

7. *Ionospheric and tropospheric delays*- The satellite signals slow down as they pass through the atmosphere. The GNSS system uses a built-in model that calculates an average amount of delay to partially correct this type of error. The atmosphere consists of several layers, and temperature varies according to these layers. Although variations do occur, temperature usually declines with increasing altitude in the troposphere which ranges from 0-10 km altitude. Nearly atmospheric water vapour or moisture is found in the troposphere. The ionosphere is a layer of

ionized air in the atmosphere extending from almost 80- 600 km above the Earth surface. Due to travel of signals through atmosphere, ionosphere and troposphere delays take place which is one of the reasons for producing the erroneous results. To determine an accurate position from range data, all these propagation effects and time offsets must be accounted for.

8. Satellite geometry- This refers to the relative position of the satellites at any given time, which may not be desirable positions, and give errors in observations. In an ideal satellite geometry, the satellites are located at wide angles relative to each other. The dilution of precision (DOP) is an indicator to the geometrical strength of the satellites being tracked at the time of measurement. Satellite geometry can affect the accuracy of GNSS positioning (Garg, 2021). Table 3.9 presents the preferred DOP value to achieve the best results. Another source of error is Geometric Dilution of Precision (GDOP) which is a measure of quality of the satellite configuration, and refers to where the satellites are in relation to one another with respect to receiver's position on the Earth (Figure 3.31). This is the spatial relationship between the GPS receiver and the satellites being tracked. The GDOP refers to three position coordinates plus clock offset in the solution. In general, the fewer the satellites available and the closer they are clustered, the more errors the readings might have. The GNSS chooses satellites that are well above the horizon, minimizing the atmospheric thickness and interference.

Table 3.9 DOP values and their ratings (Langley, 2010)

DOP value	Ratings
1	Ideal
2-4	Excellent
4-6	Good
6-8	Moderate
8-20	Fair
2-50	Poor

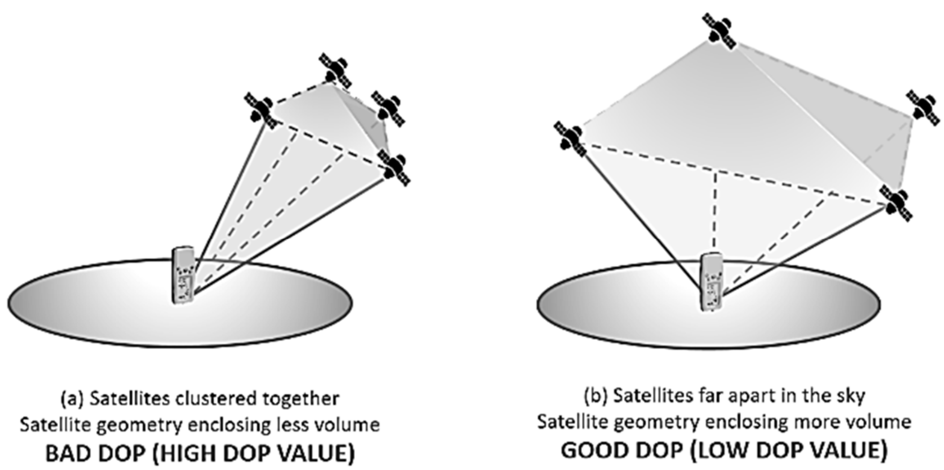

Figure 3.31 Geometric dilution of precision (Rathore, 2017)

The GDOP has two components: one is related to the receiver's position (PDOP) and the other is related to the time determination (TDOP). While PDOP is related to the satellite geometry (Figure 3.32), TDOP is strictly dependent on the time biases in the receiver and all the satellites. The PDOP value is further found to have two components: horizontal (HDOP) and vertical (VDOP), again related to PDOP orthogonally. The PDOP values between 2 and 4 is considered as excellent, between 4 to 6 is good, between 6 to 8 is fair, between 8 to 10 is poor, and 10 to 12 is marginal, and values above 12 is not recommended to use. The PDOP mask or filter can be used in receiver as a tolerance setting for acceptability of signal quality.

Overall estimate of accuracy = PDOP * GDOP (3.4)

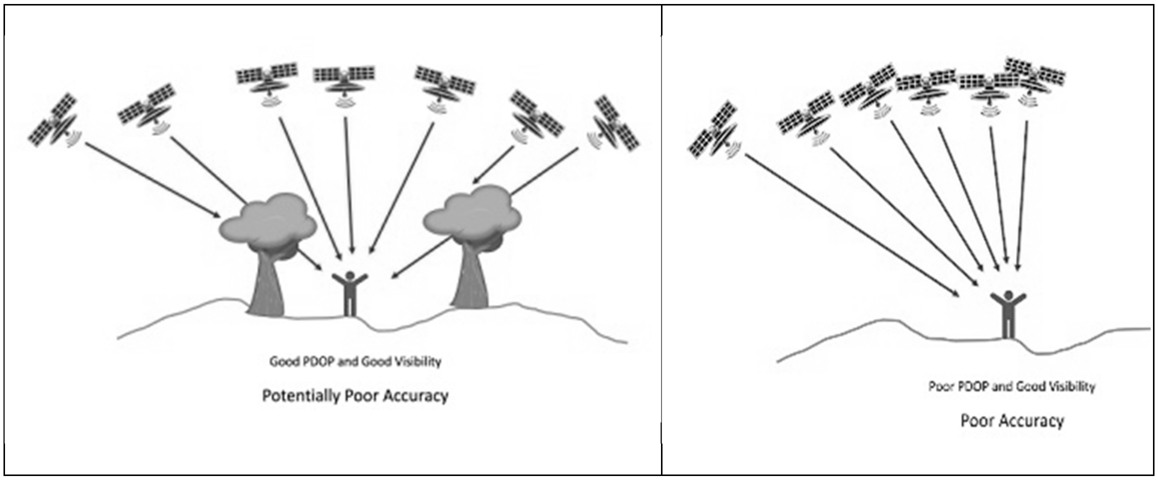

Figure 3.32 Position dilution of precision (https://www.agsgis.com/What-is-PDOP-And-Why-its-Obsolete_b_43.html)

3.4.12 Applications of GNSS technology

The GNSS has found many applications in land transportation, civil aviation, maritime, surveying and mapping, construction, mining, agriculture, earth sciences, electric power systems, telecommunications, and outdoor recreational activities (Garg, 2021). The GNSS technology has been applied in navigation, military weapons, security, location-based services, monitoring dam, bridges, dikes, landslides, and subsidence, positioning infrastructure, precision farming, forest and resource management, and many more. The GNSS networks provide valuable data for numerical weather prediction models.

The GNSS provides unique capabilities to military, civil and commercial users around the world. The US government has made the GPS signals freely accessible to anyone with a GNSS receiver. The GNSS today has become an efficient tool in the field of science, commerce, surveillance and tracking, with an accuracy of less than 1 meter. Now-a- days, GBSS are used extensively mainly by navy, airforce, army, coast guard, rescue & relief personals, civilian carriers, commercial transport, hikers, and trekkers (El-Rabbany, 2006). World-wide, there are a large number user of GPS/GNSS-enabled gadgets, like mobile phones, wrist watches etc., for a variety of applications (Xu, 2010).

Surveying and mapping: This is the most important applications of GNSS. Its use dramatically increases the productivity of mapping, resulting in collection of more accurate and reliable data in a faster way. The use of GNSS systems has revolutionized the practice of surveying. Instruments and computer software to process the results have been developed specifically for various surveying applications (Garg, 2019). Surveyors use GNSS to save time over standard survey methods. They use absolute locations to make maps and draw the property boundaries. They use GNSS receivers to survey locations that are located remotely and a direct line of sight can’t be established due to obstructions, like a mountain or forest or lake. The GNSS helps to calculate the distances and heights of different places on the Earth surface. The GNSS tool can be used to establish the Ground Control Points (GCPs) to prepare the topographic mapping of real world. Today, GNSS is a vital part of surveying and mapping activities around the world.

Navigation: The GNSS is used as an in-vehicle navigation aid, and is also used by hikers and hunters. With the help of GNSS, roads or paths available, traffic congestion and alternative routes, roads or paths that might be taken to get to the destination, can be derived. The location of food store, banks, hotels, fuel station, airports or other places of interests, the shortest route between the two locations, the different options to drive on highway, can easily be obtained using GNSS. The GNSS is used for enroute navigation and for airport or harbour approaches. Some aircrafts have been equipped with two or more GNSS antenna, and the signals from all antennas are sent to one receiver to compute the attitude of the aircraft. The aircraft also has an inertial navigation system (INS- a navigation system to sense changes in a vehicle's attitude and velocity) which along with GNSS can greatly improve the overall accurate and precise navigation.

Robotics: Just like GNSS provides direction to human, the same case applies to robots. The GNSS enhances navigation of mobile robots and makes them applicable to diverse fields such as outdoor industrial work, mapping, and agriculture. Self-navigation, autonomous robots are using the capabilities of GNSS. With the help of GNSS, the cars and trucks can work without a driver.

Road traffic congestion: A navigation device has a GPRS receiver for receiving the real-time information about the average speed on a highway, indicating the traffic congestion. The device can compute the alternate route to avoid the congestion, based on historically speed data on secondary roads weighed by the current average speed in the congestion area. Highway departments survey existing roads and planned routes with the help of GNSS.

Fleet tracking: The use of GNSS technology is helpful to identify, locate and track fleet of vehicles in real-time. Automobile vehicles, such as car, truck, ship or aircraft can have a receiver that constantly keeps a track of position. Some automobile companies connect receivers into radio systems that use satellite communications to allow one master control center to track all the vehicles in the fleet anywhere available. The GNSS tracking systems are used to route and monitor delivery vans and emergency vehicles. Many emergency vehicles have also been fitted with receivers so that the vehicle closest to an emergency could be located without losing time.

The GNSS tracker is one of the important application of GNSS technology, which is a combination of software and GNSS technology. It is a hardware device, like GNSS receiver, which can log the location data, then send the data to the server. The working principle of GNSS tracker is shown in Figure 3.33.

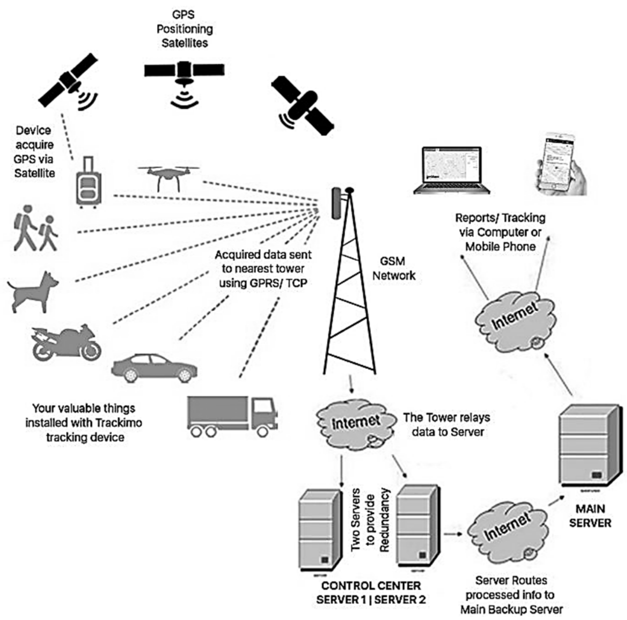

Figure 3.33 A typical architecture of a GNSS tracker system (Source: https://www.gpstracker-factory.com/gps-tracking-device-system-works/)

Tectonics: The GNSS enables direct measurement of fault movement during the earthquake, crustal motion and deformation to estimate the seismic strain built-up for creating seismic hazard maps. At the high-precision end, it is possible to measure the movements of tectonic plates, or establish major political boundaries. Receivers are able to measure the locations with a repeatability of only a few millimeters over baselines that extend several hundred kilometers. When an earthquake occurs, observations can determine which parts of the area actually moved, and in which directions and how far.

Agriculture: The GNSS-based applications in precision farming are being used for farm planning, field-based crop mapping, soil sampling, tractor guidance, crop scouting, and yield mapping. In precision agriculture farming, GNSS is used to accurately guide farm machinery engaged in ploughing, planting, fertilizing, and harvesting. Most smart phones feature GNSS map for navigation applications. The GNSS allows farmers to work during low visibility field conditions, such as rain, dust, fog, and darkness. Farmers have a specific season for planting, weeding, and harvesting, and due to the repeat in the seasons, they put the GNSS receiver on their tractors and other farming equipment which allows them to map their plantations and ensure that they return to precisely the same time when planting or weeding in the next season. This strategy is effective especially in foggy and less visibility. Its high accuracy makes it very suitable for use in mapping soil sample locations, and locating the soils suitable for a particular farming.

The combination of GNSS and GIS has given rise to the site specific farming an approach to precision agriculture. The GNSS-based applications in precision farming are used for: Farm planning, Field mapping, Soil sampling Tractor guidance, Tractor scouting, Yield mapping. Productivity can be increased with the help of precision agriculture, and the geographic information regarding the Plant-Animal-Soil requirements beforehand and then applying the relevant treatment.

Forest: Deforestation and disappearing wildlife habitats are a big problem in the modern world. Manufacturing industries use state-of-the-art GNSS technologies to produce more wood products. The rate with which large forests are being cut down for various uses is alarming than the rate at which they are being replanted, as trees take many years to grow to their full potential. The GNSS technology can make tree planting more efficient.

Defense: Army uses GNSS as a modern device for defensive purpose, like trending and rescue work. The US Department of Defense was the first to develop the GNSS system, and since then the system has been adopted by numerous military forces around the world. Today, there has been a diverse use of the app, and it can be used to map the location of vehicles and other machinery, such as missiles during a war. Military GNSS has been integrated into fighters, bombers, tankers, helicopters, ships, submarines, tanks, jeeps, and soldiers' equipment. In addition to basic navigation activities, military applications of GNSS include target designation, close air support, "smart" weapons, and rendezvous. The GBSS is very important to determine the location of terrorist attacks, and the surgical strike. This is a technique used purposely to protect the soldiers and also manage the resources.

Geo-fencing: A geo-fence is a virtual border that is set up within a GNSS unit, and the operator is informed through text or email whenever a GNSS tracker crosses the chosen region. The GNSS technology has been utilized in geo-fencing which alerts you whenever a person or object enters or exits from a chosen area.

Anti-collision device: It serves as a anti-collision device for railways and airways. It gives a warning to the driver if two GNSS-enable trains are running on the same track. To find and rescue any crashes of vehicles, trains, ship and airplanes, GNSS plays a very important role. The GNSS is used in aviation throughout the world to increase the safety and efficiency of flights. Space-based position and navigation enables determination of 3-D positions for all phases of flight from departure, enroute, and arrival, to airport surface navigation.

Mining: The development of modern positioning systems and techniques, particularly RTK GNSS, has dramatically improved various mining operations. In open-pit mines, for example, the use of RTK GNSS has significantly improved several mining operations, such as drilling, shoveling, vehicle tracking, and surveying. Satellite navigation has proven a significant increasing in productivity and improved on-site safety in mining activities, e.g., mineral and aggregate extraction with especial incidence in iron ore and coal extraction and transport tasks. In open pit mining, GNSS is very useful for tasks, such as machine guidance, grading, dozing, blasting, collision avoidance, selective mining, stock pile operations, construction of accurate benches, ramps and pads, bulk Earthworks, and rehabilitation works.

Disaster relief: The GNSS provides the location of areas where disaster relief measures could be provided. The GNSS serves as a useful tool in disaster management and rescue operations, since it provides real time situations, and the time is a critical component during the disaster. In order to save lives and reduce the loss of property, it is important to know the relevant information timely, as well as the precise location of landmarks, streets, buildings, emergency service resources, and disaster relief sites reduces the effect. The GNSS has proven to be very effective at the time of Tsunami, Katrina and Rita that have created havoc in the past in parts of the world. The rescue team with the integration of GNSS, GIS and remote sensing data planned the rescue operations by correctly locating the site and other relevant information.

Fishing: Maps of the main concentrations of fish areas, fishing ports and beach landing points, markets, processing, freezing and trans-shipment points, coastal landforms can be located with the help of GNSS. The GPS fishfinder units are significant for displaying the location of fishes. It has inbuilt features, such as maps of coastlines, rivers, and lakes as well as the resolution of nautical miles.

Astronomy: Both positional and clock synchronization data is used in astronomy and celestial mechanics calculations. It is also used in amateur astronomy using small telescope to professional's observations, for example, finding extra planets.

Unit Summary

This unit describes the modern surveying equipment used for field data collection. Firstly, EDM has been discussed along with its principle and method of observations. Secondly, Total Station is decribed. The principle used and applications of Total Stations are discuused. Various methods of observations are summarised. Lastly, the components of GPS/GNSS and working method are described. The GPS/GNSS can be used in large number of applications where location is required. These modern equipment not only require less manpower but also save lot of time and funds required to complete the survey work. The other advantage is that the data is avaiabel in digital form which can be analysed and converted into maps using the capabilities of associated software.

Exercises for Practice

(A) Short questions:

3.1 How does EDM work?
3.2 What are the different types of EDM? What is the basic difference?
3.3 Explain various components of a Total Station.
3.4 What are different measurements you take with Total Station, and what parameters you compute?
3.5 What do you understand by the terms- Ellipsoid, Geoid and Mean sea level. Draw a diagram to show the three surface.
3.6 What are the advantages and disadvantages of GNSS?
3.7 Define L1, L2 and L5 frequency in GNSS.
3.8 What is Initialization in GNSS Surveying? What do you understand by the terms- Base Station and Differential Correction.
3.9 Define the terms- Ephemeris, Epoch, Dual-frequency Receiver, Pseudorandom Noise or Number (PRN), Selective Availability, Carrier Phase in GNSS, Coarse or Acquisition (C/A) Code.
3.10 What is the basic difference between Static method and Kinetic method of GNSS data collection?
3.11 Define the following acronym as applied to GPS and GNSS
GDOP, PDOP, HDOP and VDOP
3.12 Define the following terms-
  i. Atmosphere delays
  ii. Receiver clock errors
  iii. Multipath errors
3.13 Discuss the term SBAS.

(B) Long questions:

3.14 What is the use of reflecting prism in a EDM/Total Station Survey? Show the travel of electromagnetic wave from instrument to prism and back for Time measurements, and Phase measurement.
3.15 Draw a neat sketch and show various components of a Total Station.
3.16 Discuss various steps involved in setting up a Total Station in the field.
3.17 Discuss the modalities of working with (i) normal Total Station, (ii) Reflectorless Total Station, (iii) Laser-based Total Station, and (iv) Smart Station.
3.18 Write various sources of errors in Total Station observations? How do you remove them?
3.19 Discuss the main segments of GNSS.16. Discuss the methodology of DGNSS data collection
3.20 Discuss the sources of error that affect the quality of GNSS observations. How GNSS errors can be corrected?

(C) Unsolved numerical question

3.21 A distance is measured along a slope with an EDM which when corrected for meteorological conditions and instrument constants, is 714.652 m. The EDM is 1.750 m above the ground, and the reflector is located 1.922 m above ground. A theodolite is used to measure a vertical angle of +4°25′15″ to a target placed 1.646 m above ground. Determine the horizontal length of the line.

(Ans: 712.512 m)

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