ISSN 2319 - 6629
Volume 3, No.1, December – January 2014
International Journal of Wireless Communications and Networking Technologies
Available Online at http://warse.org/pdfs/2014/ijwcnt01312014.pdf

Accuracy Enhancement Techniques for Global Navigation Satellite Systems and Its Military Ground Based Navigation Applications

Moiz Chasmai[1], Arun Barde[2], Gagandeep Purohit[3], Anjaneya Sharma[3]
[1]Research & Development Establishment (E), India, moizchasmai@gmail.com
[2]Research & Development Establishment (E), India, arunbarde@gmail.com
[3]Research & Development Establishment (E), India

ABSTRACT

Global Navigation Satellite System (GNSS) is being extensively used all across the world for precisely locating the points on the surface of the earth. Various GNSS systems are being developed by different countries; some are regional navigation systems while others cover complete globe. The accuracy of the systems varies from few metres to few centimetres; depending on the error correction techniques used. In this paper, basic concept and operation of GNSS system is explained in details with the latest updates on the current worldwide GNSS systems. This paper also covers the causes for degradation of the received satellite signals on earth and provides comprehensive accuracy enhancement techniques to overcome the effect of these errors and performance check procedures. This paper also highlights the GNSS communication standard formats for differential systems and for retrieving data from the GNSS receivers. The comparison and features of various GNSS systems have also been studied and evaluated in this paper. A separate section is devoted to the applications of GNSS for military ground based navigation systems and its future scope.

***Keywords*:**GPS, GLONASS, DGNSS, RTK, IMU

1. INTRODUCTION

GNSS is the generic term for various satellite navigation systems that provide autonomous geo-positioning with global coverage. The system is used for diverse applications that include navigation of ground vehicles, ships, aircraft & spacecraft and monitoring of shifts of the Earth's tectonic plates, etc. GNSS has risen from a mere paper design in the early 1970s to become a global utility of the 21st century. GNSS is divided into GNSS-I & II. GNSS-I is the name given to existing systems (i.e., Global Positioning System (GPS) and GLObal'naya NAvigatsiomaya Sputnikova Sistema (GLONASS)). GNSS-II includes additional second generation systems (i.e., Europe's GALILEO, China's COMPASS Navigation Satellite System (BeiDou 1 & 2), Japan's Quasi-Zenith Satellite System (QZSS) and Indian Regional Navigational Satellite System (IRNSS)) [1].

Basically, a GNSS receiver determines only four variables, namely latitude, longitude, altitude and time, which provide position accuracy from few meters to few centimetres with time accuracy of 60ns to 5ns. Other information like position, speed, etc. can be derived from these four variables. As shown in figure 1, GNSS comprises of three segments; space, control and user segments. The control stations are equipped with ground antennae and atomic clocks are spread around the globe which enables bidirectional communication with satellite [2]. The most important tasks of the control segment are to observe the movement of the satellites and compute and relay accurate orbital data (ephemeris), monitor the satellite clocks, synchronise on board satellite time, relay the approximate orbital data of all satellites (almanac) and relay information including satellite health, clock errors, etc. The Space segment consists of at least 4 satellites in space that transmits their data to the control and user segments GNSS receiver.

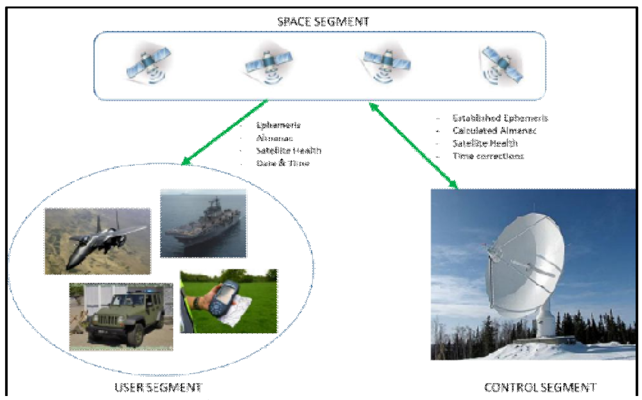

Figure 1: GNSS Segments

Each satellite (GPS & GLONASS) transmits two unique codes. For GPS, the first is called the C/A (Coarse Acquisition) code and the second code is called the P (Precise) code. These codes are modulated onto the carrier waves. C/A code is a string of 1023 digital bits in a pattern so complex that it looks random, and so is called Pseudo-Random Noise (PRN) code. There is a different C/A code PRN for each satellite. GNSS satellites are often identified by their unique PRN code which repeats itself every millisecond while P-Code takes 7 days repeating itself. The range is measured using the C/A code or the phase of the carrier wave. The GNSS receiver has a C/A code generator that produces the same PRN code as the satellite does. Code received from the satellite is compared with the code generated by the receiver, sliding a replica of the code in time until there is correlation with the satellite code, as shown in Figure 2. Similarly, for GLONASS the two codes are called Standard Precision signal (L1OF/L2OF) and High Precision signal (L1SF/L2SF).

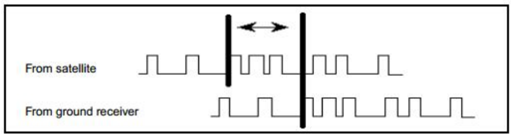

Figure 2. Code measurement

There is a time difference between the code generated at the satellite and at the GNSS receiver end. Code measurements make it possible to record this time difference. The measurements are multiplied by the speed of light (speed at which GNSS signal travels), so range can be determined. [3]

The user segment is the GNSS receiver that receives the data from multiple satellites to predict the location of the receiver.

GPS and GLONASS are fully operational and covers complete earth. Also, GALILEO & COMPASS (BeiDou 2) that will cover complete earth are under development. IRNSS, BeiDou 1 and QZSS are the regional navigation system; BeiDou 1 being fully functional and other two are under development .GNSS receivers are developed and manufactured by many firms worldwide and are commercially available.

2. CONCEPT AND OPERATION OF GNSS

The basic principle behind the unprecedented navigational capabilities of GNSS is triangulation. In three dimensional problems, any point on the sphere can be determined by its distances from three other points, based on the three dimensional triangulation method. For example, the point that we wish to determine is the location of the GPS receiver (U_x, U_y, U_z) coordinates on the surface of the earth, taking earth's centre as the origin (0, 0, 0). The satellites transmit its coordinates (X_n, Y_n, Z_n) along with their respective times(t_n) at which it sends this data as shown in figure 3. Each satellite sends two types of data; message structure and PRN code. The message structure has a basic format of a 1500-bit-long frame which is divided into sub frames of 300 bits each. These include satellite clock information, ephemeris (precise orbital data) and almanac (approximate orbital data of all satellites in the orbit). The synchronization delay (b) is calculated by comparison of bit format of satellite generated Pseudo Random Number (PRN) which is unique to each satellite and the PRN generated by the receiver on earth. The distances are computed using the travel times of radio signals and synchronization delay (b) using equation given below:

$$d = a \times (t_{rev} + b - t_{GPS})$$

Where d= distance, a=speed of light in units of earth's radius, t_{rec}=receiving time, t_{GPS}=satellite transmitting time, b=synchronization delay.

This requires accurate time keeping, prompting a slight modification of the pure spatial triangulation problem.

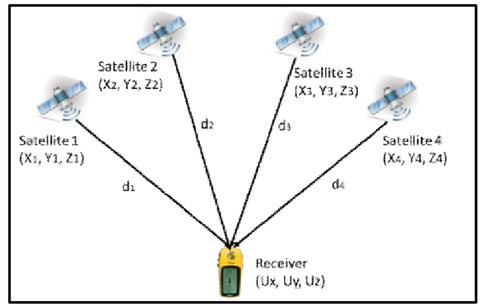

Figure 3: Basic Concept

In this case, the clocks of the satellites and the receiver are not synchronized, which will lead to incorrect distance calculation based on the time delay. Hence, apart from three unknown Cartesian coordinates of the receiver, we have one more unknown variable, i.e., time t at which the signal is received at the receiver on earth from the satellites. Hence, in the modified version, we need four satellites, rather than three, and can then calculate both the location and the correct time, at the GPS receiver [4]. The following four equations can be derived from four different satellites.

$$d_1 = \sqrt{(X_1 - U_x)^2 + (Y_1 - U_y)^2 + (Z_1 - U_z)^2} + a(\Delta t)$$
$$d_2 = \sqrt{(X_2 - U_x)^2 + (Y_2 - U_y)^2 + (Z_2 - U_z)^2} + a(\Delta t)$$
$$d_3 = \sqrt{(X_3 - U_x)^2 + (Y_3 - U_y)^2 + (Z_3 - U_z)^2} + a(\Delta t)$$
$$d_4 = \sqrt{(X_4 - U_x)^2 + (Y_4 - U_y)^2 + (Z_4 - U_z)^2} + a(\Delta t)$$

Simplifying the above equations, we get a quadratic equation in terms of receiving time t, on solving which gives two solutions for t; one of which can be eliminated as putting this time t value in the equation leads to a distance that is significantly greater than the earth's radii. Solving the equations for the other solution leads to a point on the surface of the earth, which is the actual location of the GPS receiver in Cartesian coordinates in units of earth's radius. The units of these coordinates are converted to meters and further latitude and longitude are derived using the spherical coordinate system as given in the following equations:

$$r = \sqrt{U_x{}^2 + U_y{}^2 + U_z{}^2}$$
$$Latitude = 90^0 - cos^{-1}(\tfrac{U_z}{r})$$
$$Longitude = tan^{-1}(\tfrac{U_y}{U_x})$$

where r is the distance between earth's centre and receiver.

However, the altitude measured by the GPS is not accurate as the GPS uses one of the World Geodetic System (WGS) standards which define the standard coordinate system for the earth with nominal sea level, normalizing the earth surface altitude to a standard spheroidal reference surface.

The computations explained here are not the same as the methods actually used by GPS, as here we have assumed exact geometric knowledge, whereas GNSS has to deal with real world measurement errors. Thus, GNSS typically uses more than four satellites, and a least-squares method to determine the best estimate of the location and time at the receiver. Other refinements in the actual GNSS calculations take into account the way a radio signal is impeded by passing through the atmosphere, and the actual encoding of information in the radio signal. [4]

3. TYPES OF GNSS ACROSS THE WORLD

The comparative chart of all the GNSS systems across the world is given in detail in table 1.

Table 1: GNSS Comparative Chart [5]

System	*GPS*	*GLONASS*	*COMPASS (BeiDou-2)*	*Galileo*	*IRNSS*
Country	United States	Russian Federation	China	European Union	India
Coding	CDMA	FDMA /CDMA	CDMA	CDMA	CDMA
Orbital height(km)	20,180	19,130	21,150	23,220	36,000
Orbital Period(hrs)	11.97	11.26	12.63	14.08	N/A
Evolution per sidereal	2	17/8	17/10	17/10	geo-sat
Number of satellites	24 required 30 operational 1 not used	24 operational 1 in process 2 on maintenance 3 reserve 1 on test	5 geo-stationary orbit (GEO) satellites, 30 medium Earth orbit (MEO) satellites	4 test bed satellites in orbit, 22 operational satellites budgeted	7 geo-sat
Frequency	1.57542 GHz (L1 signal) 1.2276 GHz (L2 signal)	Around 1.602 GHz (SP) Around 1.246 GHz (SP)	1.561098 GHz (B1) 1.589742 GHz (B1-2) 1.20714 GHz (B2) 1.26852 GHz (B3)	1.164–1.215 GHz (E5a and E5b) 1.260–.300 GHz (E6) 1.559–1.592 GHz (E2-L1-E11)	N/A
Status	Operational	Operational, CDMA in process	15 operational, 20 planned	Under process	1 launched 6 planned
Year of Launch	1993	2011	Expected in 2020	Expected in 2019	2014
Coverage	Global	Global	Global	Global	Regional
Accuracy	3 m <10 cm RTK	20 m (Civilian) 10 m (Military)	10 m	10 m	20m Ocean 10m land

Similar to IRNSS and QZSS having regional coverage are under development and BeiDou 1 is operational.

4. FACTORS AFFECTING GNSS POSITION ACCURACY

There are a number of factors that affects the position accuracy of GNSS signal [6](figure 4) as explained below.

4.1. Atmospheric errors

The charged ions in the Ionosphere and water vapour in the Troposphere refract the GNSS radio waves take more time to reach the earth than its actual time. The receiver eliminates the ionosphere errors by estimating the refractive index as a constant. Estimating the Troposphere correction is difficult due to dynamic weather patterns and is thus simply estimated as its effect is noticeably smaller than that caused by the ionosphere.

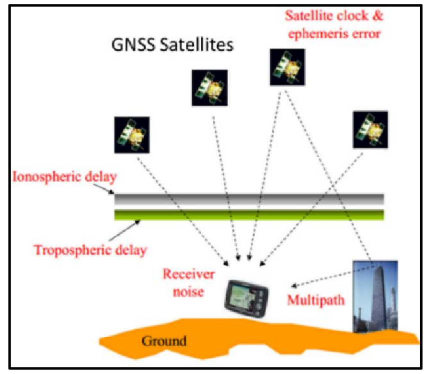

Figure 4: Various errors in GNSS data [7]

4.2. Multipath errors

These errors arise when the GNSS signals are reflected from the objects like buildings and hills while reaching the receiver. This leads to increase in the distance travelled by the signal, which in-turn leads to delay. This delay introduces an error of few meters.

4.3. Satellite orbits

Apart from the gravitational field of earth, satellites also experience the gravitational fields of moon and sun, which creates error in the orbital location of the satellites. This introduces an error of few meters.

4.4. Clock timing errors

For precise time calculations, all GNSS satellites are equipped with atomic clocks on-board. The satellites send the transmitting time of the signal to the receiver. The receiver's clock is required to be in synchronization with the satellite clock. However, in practical receiver clock is not synchronized, which introduces a timing error.

4.5. Receiver noise

As receiver is an electronic device, it suffers with inherent noises. This affects the receiver in identifying the PRN code accurately, which leads to incorrect PRN code selection by the receiver. This will give false pseudo range measurement. A good quality receiver with lower noise figure can reduce these errors.

4.6. Relativistic effects

Einstein's theory of relativity states that time appears to run slower on objects that are moving relative to the viewer. This effect makes clocks on board the satellites appear to run around 7.2 µs slower per day. It also states that time appears to run slower on objects that are in a stronger gravitational field which makes clocks on board satellites appear to run around 38.007 ms faster than those on earth.

The net result is that the clocks on board the satellites appear to run about 38ms per day faster than those clocks on earth, the resulting error is roughly 10 km if not accounted for. To account for this error the clocks on board the satellites are fitted with 10.229999995453 MHz oscillators and treated as if they were running on 10.23MHz. [6]

For applications requiring high accuracy, GNSS needs advanced augmentation systems to correct the computed transit time to compensate for these delays. Various accuracy enhancement techniques are discussed in the next section.

5. GNSS ACCURACY ENHANCEMENT TECHNIQUES

There are a number of techniques for reducing dilution and improving data quality. The signals sent from the satellites are accurate to the centimetre scale. This accuracy is downgraded by the various factors discussed in the previous section.The most common methods for improving data are discussed below:

5.1. Averaging

When a GNSS records a location it will lie a certain distance from the true location. This ‘dilution of precision’ is random but multiple readings will plot within concentric ellipses forming Gaussian distributions. This requires a substantial amount of data to be collected at each point for a significant statistical analysis to take place. Averaging improves the accuracy considerably but requires more time to be spent at a site to record data.

5.2. Differential GNSS (DGNSS)

When the radio signals reach the Rover receiver from the satellites, it has passed through the ionosphere that attenuates the signal by increasing the travel time introducing the error in few meters. This error can be eliminated by using Differential GNSS technique as shown in figure 5. Here, one more receiver called Base Station is setup which is placed at an accurately known location, near the first receiver.

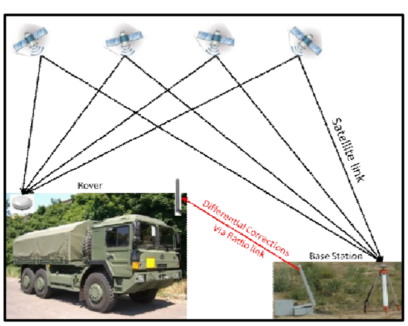

Figure 5. Differential GNSS Setup

Base station coordinates are one time setup with reference to the Ground Control Point (GCP) established by the respective Survey Departments all across the countries. Two GNSS receivers, one at the GCP and the other at the point whose coordinates are to be measured (base station), are turned ON and the satellites data is logged for around 1 hour simultaneously. Offline post processing of this data gives the accurate location of the base station for which survey was carried out. This point can then be used as a Base Station for Differential error correction. GCPs are setup using International Ground Points (IGP) which are located all across the continents.

For receivers located in geographically nearby areas, the signal to each receiver will have passed through essentially the same part of the ionosphere and be attenuated in the same way. In this case, the error of the received signal from the satellite at the Base Station is calculated by measuring the difference between the known coordinates and the coordinates data received from the satellites. This deviation is transmitted to the main receiver via radio modems of suitable frequency to correct the error of the signal received from the satellites in real time. The acceptable distance between the base station and the receiver depends on the frequency used, data rate, power level and the physical location of the antennas. This reduces the GNSS error to less than 40cm.

5.3. Precise Point Positioning (PPP)

It is a technique to calculate the precise location of a point using a single GNSS receiver which can be double or single frequency. The principle of the PPP method is to model and correct error sources instead of differencing measurements. This method employs readily available satellite orbit and clock correction data to perform absolute positioning. PPP provides a positioning solution in a global reference frame such as the International Terrestrial Reference Frame (ITRF). [8] It is cost effective since there is no need for data from local or regional reference stations. It works with single GNSS receiver unlike DGNSS which requires two GNSS receivers. The accuracy that can be achieved using PPP is upto few centimetres. The main disadvantage of using this technique is that it requires more time to converge in order to ensure centimetre-level positioning accuracy. It can take few hours to give centimetre level accuracy [9].

5.4. Augmentation Systems

Augmentation of GNSS is a method of improving the navigation system's attributes, such as accuracy, reliability, and availability, through the integration of external information into the calculation process.

(a) Ground Based Augmentation System (GBAS): GBAS is commonly composed of one or more accurately surveyed ground stations, which take measurements concerning the GNSS and transmits this information directly to the end user on radio link. GBAS networks are considered localized, supporting receivers within 20 kilometres, and transmitting in the VHFor UHF bands. Unlike DGNSS, GBAS ground stations are not setup for individual’s purpose. It is established for naval or flight landing applications.

The system uses GNSS (GPS or GLONASS) signals to provide aircraft with very precise positioning guidance during the final stages of an approach, both horizontal and vertical, which is especially critical during the landing phase of flight. A single GBAS ground station typically provides approach and landing services to all runways at the airport where it is installed.SCAT-I (Norway), LAAS (U.S.), GRAS (Australia) are some of the GBAS available globally.

(b) Satellite Based Augmentation System (SBAS): It is an augmentation system to improve the accuracy of the GNSS receiver. In DGNSS the base station receiver, placed on the ground in the vicinity of the rover GNSS is used for differential error correction. In a way, SBAS is similar to DGNSS as it also uses another reference for error correction, but here the reference is another satellite. SBAS delivers error corrections, extra ranging signals and integrity information for each GNSS satellite being monitored. Like GBAS it also augments GNSS signals to provide aircraft with very precise positioning guidance, both horizontal and vertical. However, SBAS differs from GBAS in that it provides GNSS integrity monitoring via satellites, rather than from the ground and potentially provides coverage for a wider geographical area.

SBAS comprises of a network of ground reference stations to monitor GNSS signals, master stations that collect and process reference station data and generate SBAS messages, uplink stations that send the messages to the geostationary satellites and transponders in the geostationary satellites that broadcast the SBAS messages. Worldwide, there are many SBAS systems developed by countries, namely Wide Area Augmentation System (WAAS) developed by government of US, GAGAN developed by India, EGNOS by EU and MSAS by Japan. There are other few SBAS systems developed by private organizations, namely StarFire and OmniSTAR developed by US firms. In case of non-availability of satellites for corrections in Star fire and Omni star, the corrections can also be obtained through internet. These SBAS systems need licence for usage. The GNSS receivers that are compatible to these SBAS systems and have complied with the licence can also work in stand-alone mode even if the link of the rover GNSS with the base station is lost.

(c) Real Time Kinematics (RTK): Unlike previous techniques, RTK utilizes the signal received from the satellite and not the information it carries in it. It requires base station and a rover receiver.The PRN code emits a bit every microsecond. Within a microsecond light travels 300 m, which is a very large error. High quality receivers can measure to within 1-2% of this but that error is still very large (3-6 m). The carrier wave alone is useless for timing because each wave looks essentially identical but carrier wave processing combines the pseudo random code and the carrier wave to determine a more precise location. Carrier wave post-processing can get positional resolutions down to 1-3 % of the frequency of the signal but this requires significant post processing. The realistic maximum resolution is 20-30 cm wavelength of the signal, but is commonly around 1m. [10]

In case of RTK (without post-processing),cm level accuracy can be achieved. GNSS receivers measure the difference in carrier phase cycles and fractions of cycles over time by tracking the carrier signals at both the receivers at the same time. Changes in tracked phase are recorded over time. Ranges are determined by adding the phase difference to the total number of waves that occur between each satellite and the antenna as the wavelengths of both the carrier waves are already known.

Carrier phase observables provide true range, the exact number of wavelengths from the antenna phase centre to the satellite, between two receivers [3]. Integer ambiguity search; a method to compute the number of cycles of the carrier signal between satellite and the receiver, is calculated at the receiver. Two receivers; base station and rover simultaneously track at least same four satellites. The position of one GNSS receiver is relative to another. Using RTK one can practically achieve an accuracy in cm.

6. PERFORMANCE CHECK

In order to check the performance of single GNSS receiver it is kept at pre known location (GCP). The location is measured in terms of Longitude and latitude. The variation of the measured location from the actual known location is the accuracy of the receiver.

In case of Differential GNSS, accuracy performance check of the receivers can be carried out in the following ways:

6.1. Position accuracy test for distance measurement

To evaluate the position accuracy of DGNSS system, the base station is kept at GCP and few check points are marked with known inter distance for rover receiver. The position observations are taken at each point and error is computed in terms of distance in meters.

In house experimentation was carried out for the same in RTK mode. Initially, the base station was set and the 6 points were marked on the ground at a fixed spacing of 5 metres each. At each point, rover receiver observations were taken and the distances were computed by converting these latitude-longitude readings into distance (meters). The collected data and the derived distances are given in Table 2. Here, the maximum error in the position is 0.1067 m and average error is 0.0284 m, which is acceptable for military ground based applications.

Table 2: Distance accuracy test readings

Base Station: 18.584498101N, 73.882155539E			
Locations	Readings	Measured Dist. (m)	Actual Dist. (m)
1	18.58418642N, 73.881541677E	-	-
2	18.584231087N, 73.881546844E	4.9412	5
3	18.58427642N, 73.881552677E	5.0227	5
4	18.584320587N, 73.88155834E	4.8933	5
5	18.58436592N, 73.881564677E	5.03	5
6	18.584410753N, 73.881570677E	4.9706	5

6.2. Position repeatability test over a time period

With time, the constellation of GNSS satellites will change. Hence, the communication with previous satellites are lost and the receiver will acquire the data from new satellites. To validate the position repeatability of the receiver with time, we have to take measurements at regular intervals. Now, with the compatibility of today's receivers with both GPS and GLONASS, the receivers track more than 4 satellites at a time. This reduces the time to switch satellites.

6.3. Position repeatability test after repositioning

Position accuracy repeatability has to be checked for smooth functioning of receiver .It also quantify rousing error during positioning the receiver. Following process is carried out for in house experiment in RTK mode.
Three positions A, B and C are marked and observation are recorded. Again the receiver was kept at all these positions and the observations were taken in terms of latitude-longitude. Both the observations at each point are compared to establish the repeatability. The sample data collected is given in Table 3. With RTK corrections, the average variation calculation is 0.0705 m and the maximum variation calculated is 0.1039 m.

Table 3: Repositioning Data

Points	First Reading	Second Reading	Error (m)
A	18.584365753N, 73.881564511E	18.58436592N, 73.881564677E	0.10389103
B	18.584410253N, 73.881570677E	18.584410753N, 73.881570677E	0.02587556
C	18.58427642N, 73.881552677E	18.584276087N, 73.881553344E	0.08192364

6.4. Position repeatability test after re-acquisition

In RTK mode, after getting a fix at a given position the receiver is turned OFF and restarted to get the new fix. The readings are compared to get the position repeatability. It takes few seconds to give stable and accurate reading after reacquisition.

7. GNSS COMMUNICATION STANDARD

Since all GNSS manufacturers have their own proprietary formats for storing, interfacing and transmitting GNSS data formats, it gets difficult to combine data from different receivers. To overcome these limitations, a number of research groups have developed standard formats for various user needs, namely, RINEX, NGS-SP3, RTCM SC-104, and NMEA 0183 [11].

7.1. RINEX (Receiver Independent Exchange Format)

RINEX is ASCII data interchange format for satellite navigation system data. The latest available version is 3.02, most common being 2.11 [12]. It stores the measurements from pseudo-range, carrier-phase and Doppler systems for GPS, GLONASS, Galileo, Beidou, QZSS, along with data from WAAS and SBAS.

7.2. NGS-SP3 (National Geodetic Survey: Standard Product #3)[13]

The SP3 file is an ASCII file that contains information about the precise orbital data and the associated satellite clock corrections. It is used for both the position (P) mode and the velocity (V) mode. The format is finalized by the National Geodetic Survey. The SP3 format is precise to 1mm and 1 picosecond. If velocity is included, its precision is 10E-4 mm/sec and 10E-4 picoseconds/s.

7.3. RTCM SC-104 (Radio Technical Commission for Maritime services)

It is a standard that defines the data structure for differential correction information for a variety of applications. It has become an industry standard for communication of correction information. RTCM is unreadable with a terminal program as it is a binary data protocol. All GNSS receivers support RTCM v2.x messages for DGNSS positioning. However, it does not support RTCM v2.x messages for RTK positioning. RTCM v3.x messages are suitable for RTK positioning. The error correction data sent by this differential GNSS protocol is quite heavy; it requires at least 19.2kbps of bandwidth for data transfer in RTK mode. Here, a radio frequency of UHF or higher is required to achieve this data rate. RTCM's standard supports very high accuracy navigation and positioning through a broadcast from a reference station to mobile receivers [14]. These messages contain information such as the pseudo-range correction (PRC) for each satellite in view of the reference receiver, the rate of change of the pseudo-range corrections (RRC), and the reference station coordinates.

7.4. NMEA 0183 (National Marine Electronics Association)[15]

The NMEA 0183 standard defines an electrical interface and data protocol for communications between marine instrumentation which is now commonly being used in all GNSS applications. The GNSS data is communicated to other devices, namely GIS, data logging device, etc. using NMEA 0183 standard. Generally, all the commercially available GNSS gives output in this format on either serial (RS-232/RS-422) or Ethernet port. NMEA 0183 allows a single talker and several listeners on one circuit. It employs an asynchronous serial interface with baud rate of 4800. GGA message consisting of Global Positioning System Fix Data, Time, Position and fix related data and GLL consisting of Position data: position fix, time of position fix, and status are two of the most commonly used NMEA messages. Each message can be as long as 83 bytes.

8. APPLICATIONS IN GROUND VEHICLES NAVIGATION

As GNSS such as GPS have grown more pervasive, the use of GNSS to automatically control ground vehicles has drawn increasing interest. From autonomously driven vehicles to automatically steered farm tractors, automated object laying equipment, handheld object retrieval equipment and military unmanned ground vehicles, practical and potential applications of GNSS to ground vehicles abound. [16]

Inertial systems when integrated with the GNSS can give higher sampling rate than when it is used alone. There are various military applications in which high sampling rate is required with high accuracy. Basically, IMU is a self-contained navigation device which uses 3-axis accelerometers, gyroscopes and magnetometers to track the position, orientation and direction of an object relative to a known starting point, orientation and velocity. IMU usually can provide an accurate solution only for a short period of time. Over the time, inertial sensors drift from their pre-set alignments as the initial alignment may get corrupt by vehicle motion, with imperfect transfer of alignment and velocities to the IMU. In such case, IMU can benefit from GNSS in a way that GNSS resets the IMU data and corrects the drift error periodically using mathematical algorithms, such as Extended Kalman Filter (EKF) [17] or the Unscented Kalman Filter (UKF) [18]. Also, it is possible that in certain conditions signal of the GNSS may be lost for a while. In such case, the IMU can give the position data for some duration of time (few seconds) using accurate successive approximation method. The integration between the GNSS and IMU leads to accurate navigation solution by overcoming each of their respective shortcomings.

Recent advances in the construction of MEMS devices have made it possible to manufacture small and light inertial navigation systems. With integration of GNSS with IMU, even cheaper IMU devices can be used without degrading the accuracy of the overall system. The integrated systems are used in crucial high dynamic applications like tactical and strategic missiles guidance, navigation of aircrafts and Unmanned Aerial Vehicles.

The data recorded using GNSS can be used to assist the driver for rover applications, where the GNSS data can be displayed on the digital (raster) or army maps. It can be used by the commander to plan the route and plan waypoints along the route, follow the planned route and also record the events along the route. The system that supports this kind of application is called Geographic Information System (GIS); a computer based system which provides an electronic representation of information, called spatial data, about the Earth's natural and manmade features, references these real-world spatial data elements to a coordinate system. ArcGIS is one of the platforms on which such applications can be built for navigational aid applications.

9. FUTURE POTENTIAL

With the increasing development in this field, more GNSS signals and codes will provide the user with more options and greater confidence in the positioning results. The benefits for the high precision users will be improved position reliability, precision and ultimately productivity. The greater availability of GNSS signals and codes couples with smaller, lighter and more capable GNSS receivers are paving the way for adoption of precise positioning technology in an increasing number of applications. Continuing developments in receivers and sensor integration provides improved positioning in satellite obstructed locations such as urban canyons, near buildings and under foliage. Achieving instantaneous centimetre accuracy without the need for correction data from local base stations is one of the killer applications in the near future. The main challenges facing manufacturers will be a smart selection from more than 100 available signals while maintaining acceptable power consumption. New satellites will be launched and new signals will be implemented by the GPS, GLONASS and GALILEO responsible authorities in the near future. Rather the barrier to overcome is cost. These breakthrough technologies are increasingly adding value and reshaping very traditional applications.

The same limitations such as the need of line-of-sight between the GNSS antenna and the satellite will also apply in future for RTK applications. Post-processing techniques used few years ago is now more and more requested in real-time in the field, primarily for productivity reasons. This trend applies mostly to man carried applications in land surveying and GIS and for various accuracy ranges down to the centimetre level. The latter change is also helped by the large deployment of reference station networks which offer RTK corrections through GPRS. With that signal in space and no requirement to set-up a base station, the complexity barrier to accuracy is lifted and new applications will emerge that we may not even know about today [19].

10. SUMMARY

GNSS system in today's world has become a necessity in military as well as commercial applications for navigation purpose. In today's time, GNSS accuracy can support a large number of precise navigation and timing applications. However, the augmentation systems are aimed to improve the performance of the GNSS systems even further. Various accuracy enhancement techniques are available that can negate the errors introduced by different entities in the satellite data during transmission. In military ground based navigational applications, GNSS with RTK corrections can be used to give an accuracy of sub-decimetres; where RTK corrections can be availed using either DGNSS or SBAS with RTK fix. With such accuracies, the GNSS system has a vast application in the military ground based navigation systems along with its applications in other streams.

ACKNOWLEDGEMENT

The authors are grateful to Dr. S Guruprasad, Director, R&DE (E), Pune for allowing us to publish this work. We express our sincere thanks and appreciation to Mr. VV Parlikar and Mr. AN Ansari for their constant encouragement, guidance and scientific discussions.

REFERENCES

1. A Brief History of Global Navigation Satellite Systems, The Journal Of Navigation, The Royal Institute of Navigation, Vol 65, No. 1, Jan 2012, pp. 1
2. Jean Marie Zogg, GPS Basics: Introduction to the system application overview, 2002, GPS-X-02007

3. Real Time Kinematic Surveying: Training Guide, Trimble, Part No. 33142-40, Revision D, September 2003
4. Dan Kalman, An Underdetermined Linear System for GPS, The College Mathematics Journal, The Mathematical Association of America, Vol 33, No. 5, November 2002
5. http://en.wikipedia.org/wiki/Satellite_navigation
6. http://precisiontracking.com.au/blog/factors-affecting-gps-accuracy/
7.SpletterDeutschesZentrumFürLuft-und Raumfahrt (DLR), ARAIM: Utilization of Modernized GNSS for Aircraft-Based Navigation Integrity Alexandru (Ene)
8.AlttiJokinen, ShaojunFeng, Precise Point Positioning and Integrity Monitoring with GPS and GLONASS
9. Chris Rizos, Volker Janssen, PPP versus DGNSS
10. Field Techniques Manual: GIS, GPS and Remote Sensing, Chapter 6, The Global Positioning System (GPS): Principles & Concepts
11. Ahmed El-Rabbany, Introduction to GPS: The Global Positioning System, Mobile Communications Series, Artech House, Boston-London
12.Werner Gurtner, Astronomical Institute, University of Berne, Lou Estey, UNAVCO, Boulder, Co., 10 Dec 2007.
13. Paul R. Spofford, The National Geodetic Survey Standard GPS Format SP3, National Geodetic Survey, National Ocean Service, NOAA, Silver Spring, USA and Benjamin W. Remondi, Dickerson, Maryland 20842, USA
14. RTCM Paper 156-2013-SC104-PR, NEWS from the Radio Technical Commission for Maritime Services (RTCM), July 18, 2013
15. Klaus Betke, The NMEA 0183 Protocol, August 2001
16.David M. Bevly and Stewart Cobb, GNSS for Vehicle Control, Artechhouse.com,pg viii
17. Kalman, R. E.; R. S. Bucy. "New Results in Linear Filtering and Prediction Theory". Journal of Basic Engineering (Trans. of ASME) 83: pp 95–108,1961.
18.Julier, S.; J. Uhlmann. "A New Extension of the Kalman Filtering to Non Linear Systems". SPIE Proceedings Series 3068, pp 182–193, 1997.
19.Answers of Five Leading Companies: The Future of GNSS Applications, Geo Informatics, pp 44-48, 2007