THE GLOBAL POSITIONING SYSTEM
AND
ITS APPLICATIONS

Prof. Madhav N. Kulkarni, ***Lt. Col.(R)***

kulkarni@civil.iitb.ernet.in

Department of Civil Engineering
Indian Institute of Technology, Bombay.
Powai, MUMBAI – 400076.

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Abbreviations

C/A Code	Coarse Acquisition Code
DMA	Defence Mapping Agency, U.S.A.
DoD	Department of Defense, U.S.A.
DGPS	Differential Global Positioning System
EDM	Electronic Distance Measuring instrument
GIS	Geographical Information System
GDOP	Geometric Dilution of Precision
HDOP	Horizontal Dilution of Precision
IGS	International GPS Service for Geodynamics
ISS	Inertial Surveying System
MCS	Master Control Station
MSs	Monitor Stations
NASA	National Aeronautical and Space Administration, U.S.A.
NAVSTAR GPS	Navigation Satellite Timing & Ranging Global Positioning System
NCC	NAVSTAR Control Centre
NGS	National Geodetic Survey, U.S.A.
NNSS	Navy Navigation Satellite System
NSWC	Naval Surface Weapons Centre
P Code	Precision Code
PDOP	Position Dilution of Precision
PPS	Precise Positioning System
PRN	Pseudo Random Noise
SLR	Satellite Laser Ranging
SPS	Standard Positioning System
SV	Space Vehicle
ULS	Up Load Station
UTC	Universal Coordinated Time
VDOP	Vertical Dilution of Precision
VLBI	Very Long Baseline Interferometry
WGS	World Geodetic System

THE GLOBAL POSITIONING SYSTEM AND ITS APPLICATIONS

1. INTRODUCTION

The Global Positioning System (GPS) is a satellite-based navigation and surveying system for determination of precise position and time, using radio signals from the satellites, in real-time or in post-processing mode. GPS is being used all over the world for numerous navigational and positioning applications, including navigation on land, in air and on sea, determining the precise coordinates of important geographical features as an essential input to mapping and Geographical Information System (GIS), along with its use for precise cadastral surveys, vehicle guidance in cities and on highways using GPS-GIS integrated systems, earthquake and landslide monitoring, etc. In India also, GPS is being used for numerous applications in diverse fields like aircraft and ship navigation, surveying, geodetic control networks, crustal deformation studies, cadastral surveys, creation of GIS databases, time service, etc., by various organisations.

The Navigation Satellite Timing and Ranging Global Positioning System (NAVSTAR GPS) developed by the U.S. Department of Defense (DoD) to replace the TRANSIT Navy Navigation Satellite System (NNSS) by mid-90's, is an all-weather high accuracy radio navigation and positioning system which has revolutionised the fields of modern surveying, navigation and mapping. For every day surveying, GPS has become a highly competitive technique to the terrestrial surveying methods using theodolites and EDMs; whereas in geodetic fields, GPS is likely to replace most techniques currently in use for determining precise horizontal positions of points more than few tens of km apart. The GPS, which consists of 24 satellites in near circular orbits at about 20,200 Km altitude, now provides full coverage with signals from minimum 4 satellites available to the user, at any place on the Earth. By receiving signals transmitted by minimum 4 satellites simultaneously, the observer can determine his geometric position (latitude, longitude and height), Coordinated Universal Time (UTC) and velocity vectors with higher accuracy, economy and in less time compared to any other technique available today.

GPS is primarily a navigation system for real-time positioning. However, with the transformation from the ground-to-ground survey measurements to ground-to-space measurements made possibly by GPS, this technique overcomes the numerous limitations of terrestrial surveying methods, like the requirement of intervisibility of survey stations, dependability on weather, difficulties in night observations, etc.. These advantages over the conventional techniques, and the economy of operations make GPS the most promising surveying technique of the future. With the well-established high accuracy achievable with GPS in positioning of points separated by few hundreds of meters to hundreds of km, this unique surveying technique has found important applications in diverse fields.

2. SYSTEM DESCRIPTION

2.1 General

The NAVSTAR Global Positioning System is a satellite based navigation system being developed and maintained by the DoD since 1972, for providing extremely accurate 3-D position fixes and UTC information to properly equipped users anywhere on or near the Earth, at any time, regardless of weather conditions. Uncertainties in positions of GPS satellite and timing signals, imposed due to security reasons by DoD, and other error sources, are expected to limit accuracy of determination of absolute position of observation station in real time mode to few meters, with few minutes of observations; however, various modes of observations and data analysis available and being developed, would yield accuracies better than few mm. in relative positions for base lines up to 2000 km, with few hours of observations, at minimum cost. The system consists of three segments: Space Segment, Control Segment and User Segment. The satellites continuously transmit dual frequency navigation signals consisting of information of satellites position with time tag, along with other data, which is periodically uploaded in satellite memory from the Control Segment. The User Segment receives navigation signals from at least 4 satellites, available any time globally, allowing the user to simultaneously solve 4 independent range-difference equations to yield his position - latitude, longitude and height and also the time. The versatility, accuracy, cost-efficiency and economy offered by the system make GPS the most suitable system for many different applications in various fields.

2.2 Historical Background

The TRANSIT NNSS - the satellite navigation system operational prior to GPS, was launched in 1958 by the U.S. Navy. It became operational in 1964 and was made available to civilian users in 1967. The system, comprising 5 satellites at 1075 km altitude, was phased out in the early 90s. This system has now been replaced by the NAVSTAR GPS in an extensive multi-billion dollars project launched in 1972 as a Joint Services Program of U.S. Air Force, Navy, Army, Marines and Defence Mapping Agency; in three phases. The GPS system became fully operational and available to the commercial users by early 90s.

2.3 GPS Segments

The Global Positioning System basically consists of three segments: the Space Segment, The Control Segment and the User Segment.

2.3.1 Space Segment

The Space Segment contains 24 satellites, in 12-hour near-circular orbits at altitude of about 20000 km, with inclination of orbit 55°. The constellation ensures at least 4 satellites in view from any point on the earth at any time for 3-D positioning and navigation on world-wide basis. The three axis controlled, earth-pointing satellites continuously transmit navigation and system data comprising predicted satellite ephemeris, clock error etc., on dual frequency L_1 and L_2 bands (see Figs. 1 & 2).

2.3.2 Control Segment

This has a Master Control Station (MCS), few Monitor Stations (MSs) and an Up Load Station (ULS). The MSs are transportable shelters with receivers and computers; all located in U.S.A., which passively track satellites, accumulating ranging data from navigation signals. This is transferred to MCS for processing by computer, to provide best estimates of satellite position, velocity and clock drift relative to system time. The data thus processed generates refined information of gravity field influencing the satellite motion, solar pressure parameters, position, clock bias and electronic delay characteristics of ground stations and other observable system influences. Future navigation messages are generated from this and loaded into satellite memory once a day via ULS which has a parabolic antenna, a transmitter and a computer. Thus, role of Control Segment is:

- To estimate satellite [space vehicle (SV)] ephemerides and atomic clock behaviour.
- To predict SV positions and clock drifts.
- To upload this data to SVs.

2.3.3 User Segment

The user equipment consists of an antenna, a receiver, a data-processor with software and a control/display unit. The GPS receiver measures the pseudo range, phase and other data using navigation signals from minimum 4 satellites and computes the 3-D position, velocity and system time. The position is in geocentric coordinates in the basic reference coordinate system: World Geodetic reference System 1984 (WGS 84), which are converted and displayed as geographic, UTM, grid, or any other type of coordinates. Corrections like delay due to ionospheric and tropospheric refraction, clock errors, etc. are also computed and applied by the user equipment / processing software..

2.4 Features of GPS Satellites

Some of the important features of the GPS satellites are as follows (see Fig. 2):

- Design Life: 5 years (with expendables stored for 7 years)
- On orbit weight: 430 kg
- End-of-life power: 400 W
- Power Source: $5m^2$ solar arrays tracking the sun and 3 Ni-cd batteries for eclipse
- 3 axis stablished, earth pointing satellites
- Navigation Pay Load: Pseudo Random Noise (PRN) signal assembly, atomic frequency standard - Cesium beam atomic Clocks accurate to 10^{-14} sec, processor and L band antenna
- Codes:
 (a) Precision (P) Code: Generated at GPS clock frequency of 10.23 MHz (equivalent to 30 m in range) interpolated to sub-meter level. Repeats itself after 267 days, resolution = 100 nanoseconds.
 (b) Coarse Acquisition (C/A) Code: Code sequence frequency of 1.023 MHz (range 300 m) interpolated to few m. Repeats itself every 1 millisecond, resolution = 1 micro second
- PRN navigation signals on two frequencies:
    (a) 1575.42 Mhz - L1 Band - Wave length 19 cm.
    (b) 1227.6 MHz - L2 Band - Wave length 24 cm.

2.5 Principle of Operation

Each GPS satellite carries an atomic clock with stability better than 1 in 10^{14}, which is used to generate dual frequency PRN spread spectrum L band navigation signals. These massages, continuously transmitted by satellite on P code and C/A code modulated on L1 carrier frequency, contain information of satellite ephemarides and satellite clock error. Remote MSs located in U.S.A. receive these massages and transfer to MCS which computes future information to be uploaded and stored in satellite memory for further broadcast. The purpose of code is to identify each satellite uniquely, to enable measurement of signal travel time and to facilitate selective denial of use to unauthorised users. The user equipment receives navigation massages from at least 4 satellites available above the horizon at any place at any time. Correlation of received code with corresponding code synthesised by receiver allows ground observer to measure transit time of signal from the satellite to the receiver, from which range to satellite can be computed. Simultaneous reception of 4 navigation signals from 4 satellites, containing information of time of transmission of code to 10 nanosecond accuracy and satellite position on basis of broadcast ephemeris enable the observer to form 4 pseudo range (actual range + offset due to user's clock bias) equations which can be solved to get the 3 parameters of the observer's position in 3 dimensions i.e. X, Y and Z in Earth-centered Cartesian coordinates, or equivalently the longitude, latitude and height above ellipsoid, and the receiver clock error.

2.6 Present Status

The GPS satellite constellation is now complete, with 24 satellites in operation and replacement satellites being launched regularly. Thus, a minimum of 4 (upto 6-8 in most cases) satellites are visible at any time from any place on the earth, to enable the observer to obtain his 3-D position in real-time. The selective availability (SA) - intentional degradation of the accuracy of the time and position information being transmitted by the satellites, was in operation, which restricted the accuracy of the absolute position obtained from the satellite to about 100 metres in real-time. This has recently been switched off by a US Presidential directive of 1st May, 2000, thus enabling the user to get absolute position accurate to about 15-20 m. However, for surveying applications, by getting the precise position of the GPS satellites from tracking data, and using relative mode, it is possible to improve this accuracy in post-processing mode to at least few centimetres, even when the SA is operative. The anti-spoofing (AS) - denial of P code to the international users, has also been made operational since early 90s; however, its effect on the accuracy of positioning in post-processing made is not significant.

2.7 Accuracies with GPS and Comparison with other Techniques

GPS is the first positioning system to offer very high accuracy in most surveying and navigational applications at very low cost and with high efficiency. Accuracies now 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)
(iii) 1-2 cm in Global surveys (1000-10000 km baseline lengths)

(For more details, see Blewitt, 1993). Such high accuracy standards make GPS suitable for various types of applications as compared to the limited range of applications of other positioning systems like terrestrial surveying techniques, Inertial Navigation System (INS), Satellite Laser Ranging (SLR), Very Long Base Line Interferometry (VLBI), etc. A graphical representation of comparison of precision achievable by GPS and other techniques is shown in Fig. V.

3. SURVEYING WITH GPS

Within the span of few years of its operation, GPS has truly revolutionised the field of surveying, with its potential to replace many conventional surveying techniques in use today. The different methods of surveying with GPS will be briefly described here, along with a review of GPS instrumentation and method of computation of geodetic and map coordinates from the GPS observations.

3.1 Methods of Observations

The different methods of observations with GPS include, absolute positioning, relative positioning in translocation mode, relative positioning using differential GPS technique, and kinematic GPS surveying technique.

3.1.1 Absolute Positioning

In the absolute positioning mode, the absolute coordinates of the antenna position (centred over the survey station) are determined using single GPS receiver, by a method similar to the resection method used in plane tabling. The pseudo ranges (the satellite-antenna range, contaminated by the receiver clock bias) from minimum four satellites are observed at the given epoch, from which the four unknown parameters - the 3-D position of the antenna (x, y, z) and the receiver clock error can be determined. The accuracy of the position obtained from this method depends upon the accuracy of the time and position messages received from the satellites. With the selective availability operational, the accuracy of absolute positioning in real-time was limited to about 100 metres, which has now improved to a about 10 to 20 metres, since the SA is switched-off. This can be further improved to few centimetres level by using post-processed satellite orbit information in the post-processing mode. The accuracy of absolute positioning with GPS is limited mainly due to the high orbit of the satellites. However, very few applications require absolute position in real time.

3.1.2 Relative Positioning

In the translocation mode (See Figs. III & IV), with two or more GPS receivers observing the same satellites simultaneously, many common errors, including the major effect of SA get cancelled out, yielding the relative positions of the two or more observing stations to a very high level of accuracy. The length of the baseline between two stations, and also the absolute position of one of the stations, if accurate position of the other station is known, can be obtained to cm-level accuracy, using carrier phase observations. In differencing mode of observations, using single difference (difference of carrier phase observations from two receivers to the same satellite), double difference (between observations from two receivers to two satellites) and triple difference (difference of double differences over two time epochs), effect of many errors such as receiver and satellite clock errors etc., can be minimised. (see Fig. VI). Use of dual frequency observations (both L1 and L2 frequencies) eliminates the major part of ionospheric effect on the signal, thus improving the accuracy of positioning. With accurate satellite orbit information, and use of such refined data-processing and modelling techniques, few mm to cm-level accuracy is possible even in regional or global scale surveys.

3.1.3 Differential GPS

A modification of the relative positioning method is the differential GPS (DGPS) technique, where one of the two receivers observing simultaneously is equipped with a transmitter and other receiver(s) can receive the messages given by this transmitter. The transmitting receiver is kept fixed on a point whose location is known to high degree of accuracy. Based upon this position, the receiver computes corrections to the range/phase observations from a GPS satellite, and transmits them to the other receiver, which can apply these corrections to improve the accuracy of its own position computed from GPS observations. Such a system is suited for applications such as vehicle guidance system, locating fishing boats close to the seashore, etc. The limited range of the transmitter restricts the use of such system to few km. However, satellite-based DGPS services, now commercially available, remove these restrictions on the DGPS technique, making possible Wide Area DGPS.

3.1.4 Kinematic GPS

In the Kinematic GPS technique, one of the receivers is in relative motion with respect to the other receiver, having been mounted either on a vehicle, ship or aircraft. Even with the difficulties encountered in obtaining the constantly changing position of the moving receiver, the method also offers some advantages over static surveying, including the ease with which the ambiguity resolution (estimating the whole number of wavelengths in the phase observable) can be done. This technique has a number of important applications, including ship and aircraft-navigation, photogrammetric survey control, etc.

3.2 GPS Receivers

A wide variety of GPS receivers are commercially available today. Depending upon the type of application, accuracy requirements and cost factor, the user can select the type of GPS receiver which best suits his demands. The receivers available cover a wide range from the high-precision Rouge receivers developed by the Jet Propulsion Laboratories, (JPL), of the National Aeronautics and Space Administration (NASA), with built-in atomic clock, to the hand-held navigation receivers used by Army personnel, mountaineers, etc., which can give the position to few-metres accuracy. Even wrist-watches with built-in GPS receivers are now commercially available (e.g.: the Casio GPS watch).

3.2.1 Navigation Receivers

These receivers are normally single-frequency, C/A code, hand-held light weight receivers, which can yield the position with a few-metres to few tens of metres accuracy. Single channel receivers, which can track 4 or more satellites by either sequential or multiplexing technique, which were more common in this category, are now being replaced by two or five channel receivers. These receivers are very much portable, weighing only few hundred grams, and are fairly inexpensive, being in the few hundred U.S. dollars price range. Examples of such receivers are the Magellan 5000 GPS receiver marketed in India by ROLTA (India), the NAVSTAR GPS PC card that can be fitted in personnel computer, marketed in India By Micronics Ltd., the Casio portable GPS receiver in a watch, etc. The accuracies in positioning obtained by these type of receivers are in the range of few tens of metres in absolute positioning (in the absence of SA), and few tens of cm in relative positioning, over short baselines of few km.

3.2.2 Surveying Receivers

The surveying type of receivers are single frequency, multi-channel receivers, which are useful for most surveying applications, including cadastral mapping applications, providing tertiary survey control, engineering surveys, etc. These are more expensive than the navigation type of receivers, and more versatile. The data from many of these receivers can be directly imported in to most commonly used GIS software packages / formats. Most of these receivers can also be used in DGPS mode. Examples of surveying receivers are the PRO-XR model of Trimble Navigation Ltd., the SR 100 model of Leica Ag., etc.

3.2.3 Geodetic Receivers

The Geodetic receivers are multi-channel, dual-frequency receivers, generally with the capability of receiving and decoding the P-code. They are heavier and more expensive than the navigation and surveying receivers, ranging from the Rouge receivers installed at the GPS tracking stations, to the portable geodetic survey control receivers. They are capable of giving accuracies of the order of few cm-level in absolute positioning with precise post-processed satellite orbit information and of few mm-level in relative positioning. Examples of such receivers are the 4000 SSE of Trimble Navigation Ltd., the WILD 200 of Leica, and ASHTECH Z-12 geodetic receivers, etc.

3.3 Computation of coordinates

From GPS observations, it is possible to obtain the Cartesian rectangular coordinates : X, Y, Z, in an ECEF global reference system. Often, the users require the coordinates of points in some local reference system - either geodetic latitude, longitude and height, or grid coordinates. Hence, transformation of coordinates from the global system to the local system is necessary.

3.3.1 Transformation from Global to Local Datum

The GPS coordinates are in the global World Geodetic System, 1984 (WGS84) developed by the Defence Mapping Agency (DMA) of U.S.A. These need to be transformed to the local datum in use in the particular country, e.g. Everest Ellipsoid in India. The transformation of coordinates involves seven transformation parameters - the three translations due to shift of origin, three rotations due to change in orientation (which are theoretically zero due to the axes being parallel) and a scale factor due to the different dimensions of the two reference ellipsoids. These transformation parameters must be estimated, using coordinates of several well-distributed stations in both the systems, in order to obtain the geodetic coordinates in local reference system. The values of these parameters, as evaluated by DMA for several local geodetic datums in the world, are given in Table 7 of [DMA, 1987], which need to be refined by rigorous computations and using additional data, in order to achieve a high level of accuracy in coordinates.

3.3.2 Geodetic Coordinates to Map Coordinates

The conversion from geodetic coordinates (latitude, longitude and height) to the grid coordinates on Indian topographical gridded maps (easting, northing and height) is described in [Thompson and Bomford, 1930]. It involves the transformation from the local geodetic system to the grid system superimposed on the map projection. The map projection used for Survey of India topographical maps is the Lambert conformal polyconic projection with two standard parallels, and the rectangular grid system is the Lambert Grid for India. Standard computer programmes are available for this transformation.

3.3.3 GPS Heights and Mean Sea Level Heights

The height deduced from GPS observations is the ellipsoidal height - height of the observation point above the reference ellipsoid. The geodetic height of a point is the geoidal height - height above the geoid, commonly termed as Mean Sea Level (MSL) height. These two are related by the simple equation:

MSL Height (h) = Ellipsoidal Height (H) - Geoidal Undulation (N)

The geoidal undulation (geoid - ellipsoid separation) is derived from astro-geodetic or gravimetric data, the accuracy of which is limited to few cm. World Gravity Models are available for computing the value of N at the observation station. Thus, the MSL heights computed from GPS data will contain the error in the value of N, limiting its accuracy. However, in differential GPS levelling, due to cancellation of a large part of this error, the relative heights can be determined to a much higher accuracy. The estimated precision of determination of heights using GPS is about 1.5 times the precision of horizontal component.

4. APPLICATIONS OF GPS

Due to the high accuracy, versatility, ease and economy of operation, and all-weather operation offered by GPS, it has found numerous applications in many fields, ranging from the mm-level high precision geodesy to the several-metre level navigational positioning. Some of these applications are:

- Establishment of high precision zero order Geodetic National Survey Control Network of GPS stations.
- Strengthening, densification and readjustment of existing Primary Control Networks using GPS stations.
- Connecting remote islands to mainland Geodetic Control Networks.
- Determination of a precise geoid using GPS data.
- Earth rotation and Polar Motion Studies from GPS data.
- Estimating gravity anomalies using GPS.
- Marine Geodesy : positioning of oceanic stations, buoys etc.
- Earthquake monitoring : Crustal movements of the order of few cm/year can be monitored using GPS method, thus making GPS most suitable for monitoring continental drifts, neotectonic / seismotectonic movement, etc.
- Vertical Control Network : High accuracy of few mm in heights achievable with GPS at much less cost and time compared to levelling to make GPS method most suitable for establishing lower accuracy vertical control networks.
- Geophysical positioning, mineral exploration and mining.
- Survey control for topographical and cadastral surveys.
- Ground control for photogrammetric control surveys and mapping.
- Offshore positioning : Shipping, offshore platforms, fishing boats etc.

- Instantaneous time transfer over trans-continental distances with accuracies of few nano seconds.
- Space craft tracking : Vector separation between GPS satellites and any other satellites can be monitored by GPS, e.g., pinpointing the location of LANDSAT etc.
- General aircraft navigation, approach to runways, navigation/positioning in remote areas like deserts, dense jungles, shaded areas of microwave, precise sea navigation, approach to harbours etc. It is expected that in 1990s most civilian aircrafts, ships, boats will be fitted with GPS equipments and even hikers, boat and car owners, truck drivers will be using it extensively.,
- Military ; Improved weapon delivery accuracies i.e. for missiles etc., for ranging in artillery, navigation for Army, Navy, Airforce - thus affecting ultimate saving of upto 1 billion dollars annually on navigation in U.S.A.
- Scientific applications, like studies related to the ionosphere and troposphere, glaciology, etc.

5. GPS IN INDIA

Developing countries like India are also entering the GPS era in a big way. Many scientific government organisations, including Survey of India, Indian Institute of Geomagnetism, Mumbai, National Geophysical Research Institute, Hyderabad, National Informatic Centre, Wadia Institute of Himalayan Geology, Dehradun, Centre for Mathematical Modelling & Computer Simulation, Bangalore, National Remote Sensing Agency, and many educational Institutes and Universities like Indian Institute of Technology, Bombay, and Kanpur, University of Roorkee, Anna University, Chennai, Indian Institute of Remote Sensing, Dehradun, etc. are involved in GPS-related activities for various applications. Training courses in GPS are also being introduced at different Institutes and Universities. Many other non-government scientific, educational and commercial organisations have also procured GPS equipments for different applications, including crustal movement studies for earthquake monitoring, National Highways project, City guide maps, GIS, etc. The Armed Forces are also in the process of adopting this new technology. The problems posed by the selective availability, the anti-spoofing and transformation of the GPS coordinates from WGS 84 to the Everest datum are being investigated, in order to ensure an economic, efficient and effective implementation of GPS technology in India. The need for establishing a national GPS centre to co-ordinate the activities of the various organisations in this field and to explore the feasibility of establishing a GPS tracking stations network in India to obtain precise positioning of the satellites is being felt increasingly.

6. CURRENT RESEARCH AREAS & FUTURE DEVELOPMENTS

The GPS revolution has opened numerous research and development areas in fields as diverse as geodesy, GIS, surveying and mapping, atmospheric research, hardware, software, etc. Many scientific and research institutions and universities in the world are engaged in intensive research activities related to GPS. With the phenomenal progress in GPS receiver hardware, new GPS observables are being developed, widening the scope of applications of this unique technique. The scientific GPS processing software available and being modified/developed, e.g. the BERNESE GPS software from University of Bern, Switzerland, GYPSY from JPL, USA, Potsdam GPS software from Germany, etc.; contribute to improving the accuracies achievable with GPS. Improvements in the GPS satellite orbit determination and ionospheric and toposphere propagation modelling are being sought at many space research centres. The use of

GPS for high precision geodetic, and geophysical applications like monitoring crustal movements with the ultimate aim of earthquake prediction, monitoring earth rotation and polar motion, has opened new era in geodynamics. The Department of Science & Technology of Government of India, and the Indian Space Research Organisation have initiated extensive GPS programmes for Earthquake monitoring. Use of GPS along with other satellite positioning systems like the GLONASS of Russia, and the proposed European system: GALELEO, is being implemented for specialized applications like civil aviation. Thus, GPS is poised to become the most revolutionary positioning technique of the new century, with its ever-widening scope.

7. LIST OF REFERENCES

1. Adam, J. (1991) edt., Proceedings of the International Seminar- GPS in Central Europe, Penc, Hungary.

2 Adam, J. et al.(1993) edt., Proceedings of the Second International Seminar- GPS in Central Europe, Penc, Hungary.

3. Anderle, R (1988), The Global Positioning System, Royal Society of London, U.K.

4. Blewitt, G.(1993), Advances in GPS Technology for Geodynamics Investigations : 1978-1992, Crustal Dynamics Project AGU Monograph, NASA.

5. Colombo, O.L. & M.M. Watkins (1991) , Satellite Positioning, in US National Report to IUGG on Geodesy.

6. DMA (1987). World Geodetic System 1984, DMA Technical Report TR 8350.2.

7. Fell, P, J. (1980), Geodetic Positioning Using GPS, The Ohio State University Report No. 299, Columbus, Ohio, USA.

8. Goad, C.C. (1985), edt., Proceedings of First International Symposium on GPS, USA

9. IGS (1999), International GPS Service for Geodynamics, Resource Information, University of Bern, Switzerland.

10. King, R.W. & others (1985), Surveying with GPS, University of New South Wales, Australia.

11. Kulkarni, M.N. (2000), Edited., The GPS and Its Applications, Training Volume, GPS Training Course, Civil Engg. Dept., I.I.T. Bombay, 9-19 May.

12. Kumar, M. (1992) edt., Proceedings of Sixth International Geodetic Symposium on Satellite Positioning, Columbus, USA.

13. Mueller, I.I. (1989) edt., Global and Regional Geodynamics, IAG Symposia 101, Springer-Verlag.

14. Thompson, Lt.Col. and Capt. G. Bomford (1930), The Lambert Grid for India, Survey of India Special Publication No.1.

15. Wells, D.E. (1988), edt., Guide to GPS Positioning, Canadian GPS Association, New Brunswick, Canada.

16. Hoffman-Wellenhof, B, et. Al. (1997), GPS Theory and Practice, 4th Rev. Edition, Springer Wien, New York.