Accuracy Aspects in the use of GPS Technology for Geoinformation System

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Abstract

In the process of rescue operations and assessment of damage to a specific location during natural and man-made disasters; maps play an important role. The developing countries like India have seen the rapid urbanization and unplanned growth of cities and this requires fast updating of various type maps related to land use. In various applications an up-to-date map is essential and modern mapping tools like remote sensing satellite images and Global Positioning System (GPS) are proving reliable and fast techniques in the development, management and analysis of Geo information system.

This research paper investigates the accuracy of hand-held L1 frequency GPS receivers (Magellan Sport track and Leica GS5). Different linear and aerial features in the study area have been digitized using hand-held GPS receivers. Accuracy of the above digitized features were determined by comparing the corresponding feature dimensions extracted from Indian Remote Sensing satellite (IRS-P6) LISS-IV sensor images and Leica make Total Station based measurements. The investigation results have shown that even a single frequency hand-held GPS in the stand-alone mode could provide planimetric accuracy in the range of 3 to 6 m. This makes the GPS a very quick and reliable tool for surveying tasks related to medium scale plannimetric map database in the development of Geo information System.

Introduction

Maps have an important role in the development and planning process and these are basic components of Geo information System. In the construction of any small or big

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project, information about the topography and land use of the site is very essential and this requires an up-to-date base map of that area (Clavet, 1993). Because of rapid urbanization in the developing countries like India, maps require frequent updating. In the many regions of the world, the large-scale topographic maps do not exist and it is necessary to carry out surveying field work for specific application (Cook and Pinder, 1996; Kardoulas *et al.*, 1996). The map data capture using conventional methods takes longer time and some alternative quick and reliable method is desirable (Katiyar, 2003).

Modern surveying equipments such as robotic total station, electronic distance measurements (EDMs) and digital and laser levels have replaced traditional surveying equipments. The main advantage of these equipments is the automation of map making process, using computer interface and high accuracy. The developments in space technology and electronic industry have given the new dimensions to the map data collection methods. The high-resolution remotely sensed imagery are playing a major role in the mapping and cartography. In order to use the remote sensing satellite images as base map, its geo referencing is essential and this process requires attaching of precise coordinates of some selected landmarks.

The most significant development of the twentieth century for the navigators was the development of the Global Positioning System (GPS) by the U.S. Department of Defence (DOD) and known as NAVSTAR (Navigation System with Time and Ranging). Civilian users quickly realized the potential for survey positioning and began using these experimental satellites to perform surveys, in spite of inconvenience as viewing times and uncertainty of signal availability (Satish Gopi, 2005). GPS can provide an alternative to the ground control survey methods for the poorly mapped areas, which could not be mapped using conventional methods and during natural calamities. Differential mode of GPS known as DGPS has the capability of providing very precise position of any point up to centimeter level accuracy (Hofmann-Wellenhof et. al, 1993). GPS has increased tremendously the application potentials of the remotely sensed images (Thapa and Bossler, 1992; Katiyar, 2003).

GPS technology has got diversified applications not only in mapping but also in precise time determination, vehicle tracking, navigation etc. After termination of selective availability (SA) of GPS signals, the hand-held GPS accuracy has improved considerably and various possibilities for the cost-effective use of GPS technology have emerged. The GPS technology could prove to be very useful in the infrastructure development and utility mapping. In the age of information and space technology, GPS could provide variety of mapping data inputs in a very short time with the desired level of accuracy, which could be directly used in the software for the map plotting and developing the Geo information System database. This research paper focuses for developing an understanding on the accuracy aspects of GPS technology, in preparing the geo information database in a cost-effective manner.

GPS Principle

The GPS receivers calculate position of the station occupied on the basis of well-known resection principle of surveying (Schofield, 2001). If the three-dimensional position of three control stations are known, and their distances (R1, R2 and R3) to an unknown station are given, then it is possible to calculate the three-dimensional position of the unknown station as shown in figure-1. In GPS control stations are satellites whose positions in the orbit are precisely known. Positioning and navigation is done by GPS receivers with the help of time-coded transmission from satellites (Katiyar *et al.*, 2002). The three- dimensional position of the ground station carrying an accurate clock can be determined if three satellites are visible simultaneously. However the clock used by receiver on the ground is normally less accurate (Kaplan, 1996). Because of non- synchronization of two clocks, the calculated distance to a satellite is not exact and is therefore called pseudo-range (R) given by following relation

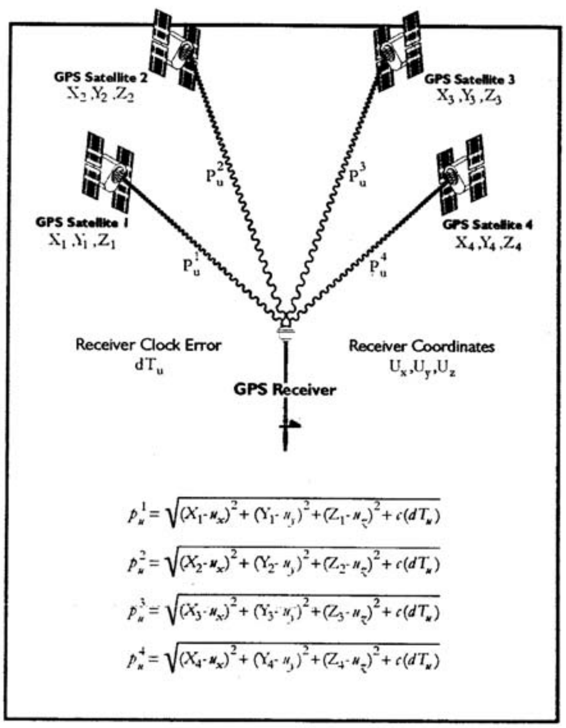

Fig1. Global Positioning System Principle (Sickle, 2001)

$$R = C(T_t - T_r) + \frac{C.A}{F^2} + T$$

Where,

C - speed of light
T_t - GPS signal transmission time
T_r - GPS signal receiving time
A - constant relating to the electron density of ionosphere
F - GPS signal frequency
T - Excess path length due to troposphere

The clock bias is a systematic error which can be determined if information from a fourth satellite can also be obtained. After knowing P_I (three-dimensional position) and RI (pseudo-ranges) from four satellites, we can uniquely solve for four unknowns which are position (X,Y, Z) of ground station and clock bias which will yield true clock time for the receiver. In the navigation mode, Doppler principle is used for the determination of instantaneous velocity of GPS receiver.

In general, GPS receivers can be divided in to two broad categories, single frequency and dual frequency receivers. The dual frequency receivers are costly, while the single frequency receivers are very cheap (costing around Rs. 15,000/-). The GPS receivers provide observations in two different modes stand alone and differential mode (DGPS) as shown in figure-2. After the termination of the selective availability (SA) of the GPS signals the accuracy of GPS measurements even in the stand-alone mode, using single frequency receivers has increased considerably (Katiyar et. al, 2002; Sateesh Gopi, 2005).

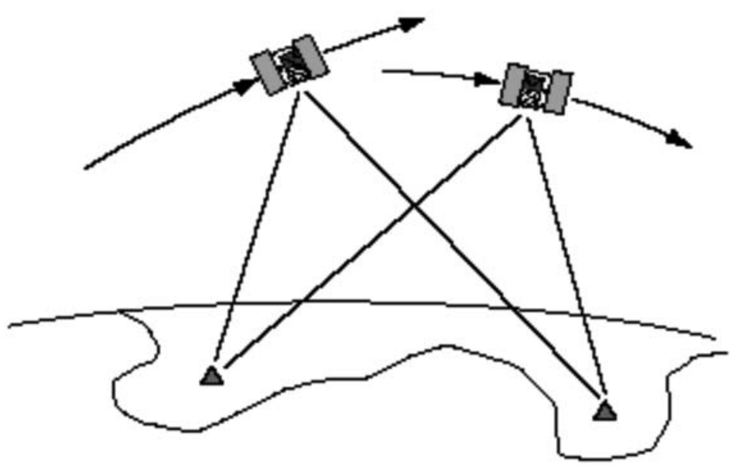

Fig 2. DGPS observation technique (Leica, 2000)

Error Sources in GPS Measurements

There are several sources of error that degrade the GPS positioning accuracy (Hofmann-Wellenhof, 1993; Kaplan, 1996; Leica, 2000). The main error sources are summarized here

Ionospheric and Atmospheric Delays

The GPS satellite signal is slowed down as it passes through the ionosphere. This action is similar to light refraction through a glass block. At night there is very little ionospheric influence and signal quality is better as compared to day time. The ionospheric errors are mitigated by using DGPS measurements.

Satellite and Receiver Clock Errors

The GPS satellite clocks are very accurate (about 3 nano seconds), but sometimes they may drift slightly. This drift in time will cause small errors, and affects the positional accuracy. Any drift in timing is corrected from GPS satellite control stations. The GPS receivers are fitted with quartz clocks, hence its time measurements are less precise and result the receiver clock errors.

Multipath Errors

Interference caused by reflected GPS signals arriving at the receiver, typically as a result of nearby structures or other reflective surfaces as shown in figure-3 is known as multipath error. Signals traveling longer paths produce higher (erroneous) pseudorange estimates and consequently positional errors.

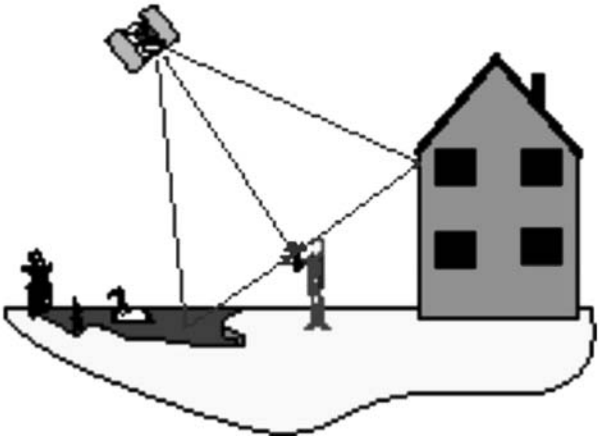

Fig 3. Multi-path errors in GPS observations (Leica, 2000)

Dilution of Precision (DOP)

The dilution of precision (DOP) is a measure of the strength of satellite geometry or a description of the geometrical contribution to the uncertainty in a position fix. This number is somewhat similar to the strength of figure in the triangulation survey (Schofield, 2001).

Selective Availability (SA)

The U.S. Department of Defence (DOD) employs a method of GPS signal degradation that limits the precision with which the C/A code may be used in navigation and positioning. This technique is called Selective Availability. The DOD can presumably control this distortion by algorithms (describing this distortion), which are available in military type receivers. The SA has been put off since May 2000.

Datum Transformations

The old series of topographic maps prepared by Survey of India (SOI) uses Everest ellipsoid, while GPS system uses WGS-84 ellipsoid. The parameters of these two ellipsoids are appreciably different and given in the (table-1). If proper attention is not given on these aspects, then a large amount of error will be introduced in the GPS observed coordinates.

Fig 4. Study are location map

Investigations

This research work presents investigations pertaining to the accuracy of a hand-held GPS receivers of Leica (GS5) and Magellan (Sport track) make in autonomous mode, by making observations at well-distributed stations in the cities Kanpur, Lucknow & Bhopal (figure-4). The investigations of this work were carried out on two different aspects, the accuracy of coordinates observed with a hand-held GPS receiver and difference of Indian datum and corresponding WGS-84 datum coordinates of various study area control points.

Fig 4(b). False color composite of Bhopal city and nearby area generated from IRS-1D, satellite LISS-III sensor imagery

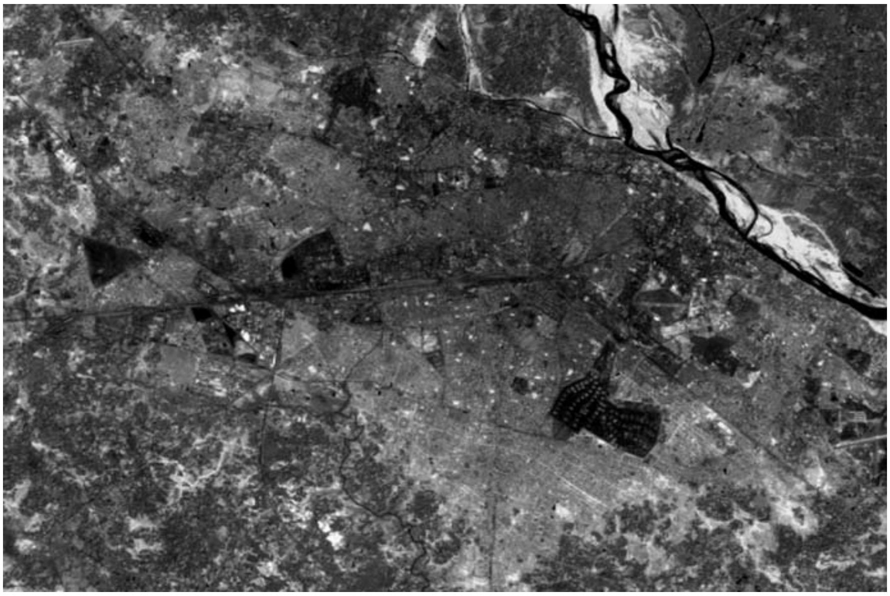

Fig 4(c). False color composite of Kanpur city and nearby area generated from IRS-1D, satellite LISS-III sensor imagery

Fig 4(d). False color composite of Lucknow city and nearby area generated from IRS-1D, satellite LISS-III sensor imagery

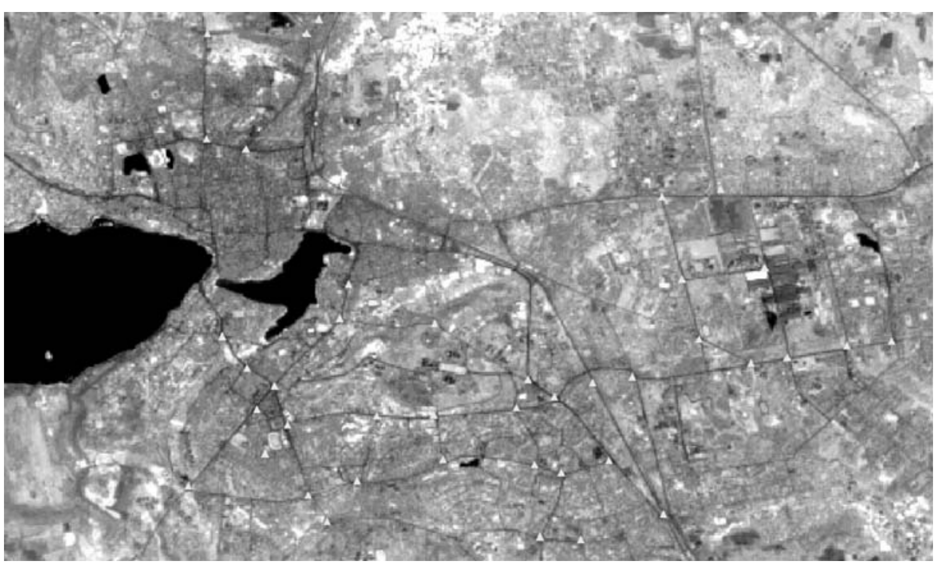

Fig 4(e). GCP's marked on the IRS-1D, satellite PAN sensor imagery of Bhopal city

Eight different stations were established at IIT Kanpur campus and various date and time observation were recorded for a period of about one month, in order to establish the average coordinates of the stations. The standard deviation of the measured planimetric coordinates and heights for these stations are shown in figure-5. These distances were measured with the help of Total Station instrument as well as on the geo referenced IRS-P6 satellite images of LISS-IV sensor. The discrepancy between observed distances using hand-held GPS and Total Station measured are shown in the figure-6.

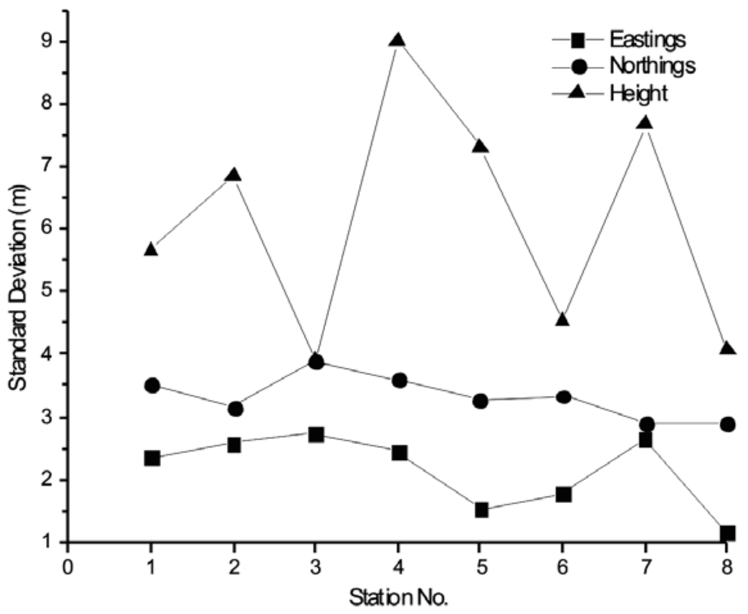

Fig 5. Standard deviation of GPS observed coordinates: eastings, northings and height above ellipsoid (H) at different stations.

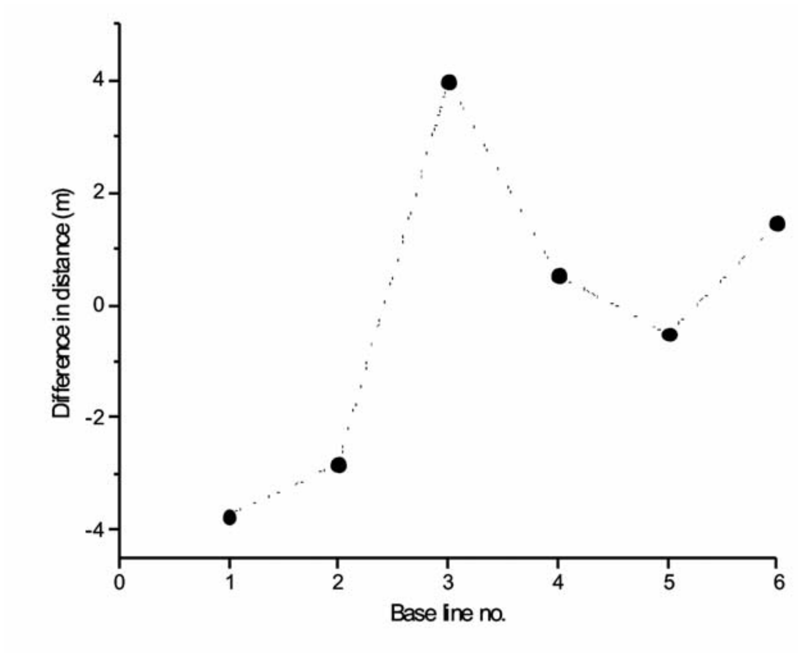

Fig 6. Difference in GPS measured and total station measured distances between different stations

For the analysis of offset between Indian and WGS-84 datum coordinates different GCPs like road and railway line intersections were selected and their coordinates were measured. These WGS-84 ellipsoid GPS observed coordinates were also compared with the corresponding Indian datum coordinates read on the 1:50,000 scale Survey of India topo sheets for the Bhopal, Lucknow and Kanpur cities and difference between these two values for 15 numbers of stations are shown in the table-2.

Table 1. WGS 84 and Everest (India 1956) ellipsoid parameters (NIMA, 2000)

Details of parameter	WGS-84 ellipsoid	Everest ellipsoid
Semi-major axis (a)	6378137.0 m	6377301.243 m
Flattening (f)	1/298.257223563	1/300.8017
Angular velocity of Earth (ω)	7292115.0 x 10^{-11} radian/s	Not available
Earth gravitational constant (GM)	3986004.418 x 10^8 m^3/s^2 ±0.1 x 10^8 m^3/s^2	Not available

Table 2. Difference between WGS-84 datum and map derived Indian datum planimetric coordinates for the study sites

GCP No.	Bhopal 1:50,000 scale map		Kanpur 1:50,000 scale map		Kanpur 1:25,000 scale map		Lucknow 1:50,000 scale map		Lucknow 1:25,000 scale map	
	$\Delta\phi$ (s)	$\Delta\lambda$ (s)	$\Delta\phi$ (s)	$\Delta\lambda$ (s)	$\Delta\phi$ (s)	$\Delta\lambda$ (s)	$\Delta\phi$ (s)	$\Delta\lambda$ (s)	$\Delta\phi$ (s)	$\Delta\lambda$ (s)
1	-3.54	3.76	-1.41	5.06	-1.31	6.05	-1.26	7.34	-1.54	7.97
2	-2.76	4.03	-2.37	5.87	-1.21	6.58	-0.54	6.61	-0.74	5.11
3	-0.99	5.66	-0.92	7.59	1.67	7.18	-0.50	7.44	-1.09	5.57
4	0.53	3.32	-0.06	6.06	-1.60	7.97	-1.28	7.19	-1.69	5.15
5	-1.67	3.62	-3.93	5.99	-0.90	6.17	-0.57	8.29	-1.33	6.01
6	-0.86	4.54	-3.07	5.88	-0.06	6.11	-1.14	6.90	-0.72	5.14
7	-1.61	3.95	-0.06	6.87	-0.41	4.35	0.04	7.41	-0.32	5.55
8	-0.53	2.49	-0.34	6.14	0.16	6.90	-0.20	7.22	-0.25	5.73
9	-0.49	2.54	-0.68	6.39	-0.98	6.01	-1.07	8.51	-1.63	6.27
10	-0.53	4.64	-1.19	6.41	-0.46	5.16	0.52	6.30	-0.57	4.76
11	-1.27	2.90	-0.15	6.39	-0.74	5.11	0.22	6.99	-0.38	4.88
12	-2.36	3.72	-1.42	6.03	-1.69	6.71	-0.73	7.50	-0.53	5.40
13	-1.23	3.43	-1.36	8.03	-0.12	6.96	-0.57	6.01	-0.09	5.96
14	-1.18	4.01	0.55	6.07	1.13	6.94	-1.77	5.99	-1.98	4.85
15	-1.07	4.55	-1.47	5.37	-1.58	6.79	-0.77	6.93	-1.23	5.98

$\Delta\phi$ Latitude difference
$\Delta\lambda$ Longitude difference
s Seconds

Conclusions

Based on the investigations of present research work, following conclusions are drawn:

- Map derived GCP coordinates should not be used for the geometric correction of modern age high-resolution images from IRS-1C/1D, IRS-P6 or any other high-resolution sensor. The GCP coordinates collected from hand-held GPS receiver would suffice the sub-pixel accuracy requirements even for IRS sensor PAN images.

- Averaging of a number of repeated GPS observations at the same station using hand-held GPS receiver can provide the accuracy in the range of 3 to 6 meters and this is appropriate for so many applications in the development of Geoinformation system database.
- In the use of GPS data, the non-availability of transformation parameters between WGS-84 and Indian datum is a big problem at least for civilian users.

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