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Value Addition to the Cartographic Potential of Satellite DataUsing Global Positioning System

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ABSTRACT

The Remote Sensing data acquired from space based platforms has demonstrated its potential in natural resources mapping, management, monitoring and developmental planning. Since the last few decades the images acquired from aerial platforms has large impact in mapping the topographical maps. Similarly, the satellite data, available with high spatial resolution, possess the high geometric fidelity and form as the basic source for generating base maps and topographic maps. The plannimetric accuracy of the aerial photos and satellite images is of prime concern for their usage in cartographic and thematic mapping. The Global Positioning System (GPS) based ground control points (GCP) are used for improving the plannimetric accuracy of the satellite images and generating value added products to facilitate cartographic mapping.

INTRODUCTION

Remote sensing (RS) data is being extensively used for natural resources mapping, management, monitoring and developmental planning (NRSA 1995). The geometric accuracy of the satellite output plays a major role in generating precise thematic maps (RRSSC 1995). Conventionally, the satellite data is georeferenced using ground control points acquired from topographical maps. The administrative boundaries and the basemap information are also captured from topographical maps. With the present day availability of high-resolution satellite data, the corresponding large-scale reference maps are not available for geo-referencing of the satellite data and capturing collateral information (Srinivasa Rao et al. 2003). Apart from this, the recent changes in the infrastructure etc., on the land are not reflected in the topographical maps. In addition to this, the map restriction policy limits the utilization of spatial information generated on Everest datum using the present day advanced technological tools. This has necessitated the search for alternate ways for basemap generation. The Global Positioning System (GPS) based Ground Control Points (GCP) can be used for enhancing the locational accuracy of the satellite data (Smith & Atkinson 2001). The precision product thus generated can be effectively utilized for cartographic mapping and thematic mapping (Kardoulas, Bird & Lawn 1996).

GEOMETRIC DISTORTIONS IN SATELLITE IMAGES

Remotely sensed images are not maps. The information extracted from remotely sensed images is to be integrated with the map data in GIS. There are various sources of errors, which degrade the geometric fidelity of the satellite data. The geometric distortion is an error on an image, between the actual image coordinates and the ideal image coordinates, which would be projected theoretically with an ideal sensor and under ideal conditions (Paul M Mather 1987). The geometric correction is undertaken to correct geometric distortions in a distorted image, and is achieved by establishing the relationship between the image coordinate system and the geographic coordinate system using calibration data of the sensor, measured data of position and attitude, Ground Control Points (GCPs), etc.

The satellite data recorded at the earth station is corrected through various levels of processing (NRSA, 1995). They are Level 0 - Uncorrected (raw data), Level 1 - Radiometrically corrected and geometrically corrected only for Earth Rotation (browse product) and Level 2 - Both radiometrically and geometrically corrected (standard product)

The desired accuracy required at 1:50,000 scale may be of the order of 1mm of the map units, i.e., less than 50 m on ground. Using precise ground control points, the desired geometric accuracy of the satellite data products can be achieved (Cook A E & Pinder J, 1996). The precision products (Level 3), generated using ground control points, will have location accuracy better than 50 meters on ground (S Srinivasa Rao et al., 2003). The number and distribution of ground control point's influence the accuracy of the geometric correction (Smith D & Atkinson, 2001).

GLOBAL POSITIONING SYSTEM (GPS)

Global Positioning System has revoluationized positioning concepts, though it is started primarily as a navigation system. It works on the principle of space resection. It has wide range of geodetic, geophysical, navigational, marine, military and social applications (Agarwal 1996).

The NAVSTAR GPS (NAVigation Satellite Timing And Ranging Global Positioning System) is a satellite based radio navigation system providing precise three-dimensional position, navigation and time information to suitably equipped users everywhere on a continuous basis. It is primarily a military system with limited access to civilian users. GPS receivers have been developed which observe signals transmitted by satellites and achieve sub-meter accuracy in point positioning and a few centimeters in relative positioning (Arnaud & A Flori, 1998). It has the following advantages over the classical methods.

- Inter visibility between points not required
- All weather operation
- Day and night operation
- Distances up to thousands of kilometers can be measured
- Fast and economical

STUDY AREA & DATA USED

The study area is located in and around Bhisi, Chimur taluk, Chandrapur district, Maharashtra. The area is 70 km away from Nagpur and lies in between 79^0 15; and 79^0 30' Eastern longitudes and 20^0 30' and 20^0 45' Northern latitudes.

From the precision product generated for the study area, the cartographic features are extracted and compared with the feature density with that of the conventional methods. The study area is chosen in such a way that it will cover good amount of features from different categories, like transportation network, drainage network, agricultural land, forest land, water body and built-up. In addition to the two-dimentional variations, the information about the third dimension is also considered while selecting the study area.

The IRS IC LISS III (Path - 100 and Row - 58) and PAN data (quadrant A) of the corresponding area are used for generating precision products. The corresponding reference maps of 55 P/6 on 1:50,000 scale and 1:25,000 scale are also used. Dual frequency & Single frequency geodetic receivers are used for GPS observations.

METHODOLOGY

The methodology for generating precision product using GPS based GCP, depicted in the Fig 1, basically consists of the following sequence of steps

- WGS-84 datum establishment
- Densifying the WGS-84 datum
- Acquisition of GPS data
- GPS data Processing
- Baseline Accuracy Evaluation
- State Level Reference Projection Grid for Generating Seamless Data Mosaic
- Transformation Model Development
- Precision Product Generation
- Merged Product Generation
- Error Budget Analysis.

WGS-84 DATUM ESTABLISHMENT

The coordinates of any point on WGS-84 datum can be acquired using GPS data in two modes, i.e., navigational solution and differential solution. In the navigated mode, absolute coordinates of the point are acquired. This process basically captures coded measurements and the processing of data is carried out in stand-alone mode. The accuracy of the coordinates is a function of Geometric Dilution Of Position (GDOP) and duration of observations and the inherent limitations of selective availability (at present is off) and anti spoofing (Arnaud & Flori; 1998, Gao Jay, 2001; Kardoulas, Bird & Lawn, 1996; Smith & Atkinson 2001). The accuracy is of the order of meters. When high-resolution satellite data is used for basemap generation, the error should be less than the order of satellite data resolution. Hence differential mode of operation, which involves processing of coded and phase measurements, will be required to get sub-meter accuracy in the location of a point on WGS-84 datum (Gao Jay 2001). For differential mode of operation, the measurements are related to a master reference point. This master reference point has to be established by acquiring lengthy observations, phase measurements using geodetic GPS receivers and processing the with reference to the WGS-84 datum world wide network and high end software packages for GPS data processing (Garg 1999).

Department of Space has established WGS-84 datum in India through 25 zeroth order points spread across the country. This network can be used for differential mode of GPS operation.

For establishing WGS-84 datum, the first task will be establishment of a reference point with accurate coordinates. A permanent monument is constructed with well-defined marking on a brass plate. The monumentation point is observed for a continuous 72 hours using dual frequency geodetic GPS receiver. Using Bernese software, the observations are processed in differential mode using post-processing data. The precise coordinate of the monumentation point is arrived at with reference to the five permanent stations of WGS 84 datum with long baselines of the order of 2000 km. The accuracy achieved for this coordinate is of the order of 0.02 ppm.

DENSIFYING THE WGS-84 DATUM

The existing zeroth order reference stations of WGS-84 datum are approximately at a distance of 300-500 km from each other. For carrying out geodetic survey, the density of the reference stations should be high for achieving high accuracy of baseline data processing (Gunter Seeber, 1993). The number of reference stations should be increased so that within a 150 km radius there exists a reference point of WGS-84 datum. The densified network will facilitate, for the next level of control points, an advantage in shorter duration of GPS data logging and improved accuracy. In Indian scenario, the densified network will provide one GPS reference point at least for 2-3 districts.

Number of ground control points

The LISS III data and PAN data of IRS 1C/1D satellite are used for precision product generation and subsequently as the base for capturing basemap details. The LISS III data will have the coverage of 141 km * 141 km, where as PAN will have the coverage of 70 km * 70 km. Both of these data sets have to be geo-referenced and merged product has to be generated.

Panchromatic data with 6 m spatial resolution is geo-referenced and subsequently LISS III data will be rectified using image-to-image registration technique using GPS based ground control points (GCP). For geo-referencing each PAN scene, a minimum of 6 points will be required for using affine transformation model. Hence, for the entire LISS III coverage, a minimum of 24 points is a must. This will generate very accurate data set, but more number of GCP's are required. This approach need more time for acquiring points and resources for meeting the requirements.

Alternatively, LISS III scene will be geo-referenced first using GPS based GCP's. This approach need a minimum of 6-9 GPS points for rectifying entire 141 km x 141 km area. Subsequently PAN data will be geo-referenced using image-to-image registration technique. The GPS points will be used for assessing the accuracy of PAN data registration and adjusting the image-to-image transformation model. However, the accuracy of the stand-alone transformation model may be high compared to the relative-transformation model. But this approach will provide fast and economical solution for generating precision products.

As the GPS will provide sub-meter accuracy in differential mode, the definition of the point on the ground as well as on the satellite image are in tune with the GPS accuracy (Srivatsava 2001). The primary characteristics of the GCP are precise boundary, good contrast on the image, identifiable on all seasons of the satellite data, approachability by road, durability of the point etc. In view of these characteristics, the intersection of village roads, railway crossings etc. are selected as candidate GCP (Kardoulas Bird & Lawn 1996).

ACQUISITION OF GPS DATA

Single frequency geodetic GPS receivers are used for acquiring geographic coordinates. Three receivers are used in synchronous mode. One receiver is operated at the Master Reference Station. The zero order monumentation points established by DOS all over India are used as Master Reference Stations. The second receiver is used as reference station, which is established for densifying the network at local area. The third receiver is used for acquiring the GPS observations at the Ground Control Point.

GPS DATA PROCESSING

The GPS data is processed using SKI-L1 process. The single frequency GPS receivers are capable of observing only data on L1 carrier wave. The precise coordinates determined earlier for Master Reference station are adopted for fixing the coordinate at the reference station. The observations at the master reference station, reference station and at the GCP are processed using baseline mode of operation (Jan Van Sickle, 1999). The options, phase measurements as well as coded measurements, are used for determining the coordinates at the GCP point (Singh, Mohanta & San Maung 1996).

Many a times, it was observed that the ambiguity was not resolved for GPS data observations. The thresholds set for GPS data processing are modified in order to solve for ambiguity resolution (Kaplan 1996). If this is not satisfactory, coded observations are used for determining the base line information.

BASELINE ACCURACY EVALUATION

The single frequency geodetic receivers are capable of providing sub-meter accuracy in differential mode (Jan Van Sickle 1999). However, sufficient number of observations are necessary for achieving the accuracy thresholds. If GPS data is available from Multiple Master Reference Stations surrounding the study area, the radius of error circle can be precisely calculated (Agarwal 1996). However, based on the one reference station, only the rms error can be calculated to measure the accuracy of the baseline vector.

STATE LEVEL REFERENCE PROJECTION GRID FOR GENERATING SEAMLESS DATA MOSAIC

The operational use of RS and Geographical Information System (GIS) technologies across the globe for various natural resources mapping, monitoring, management and subsequent developmental planning as necessitated the design and development of spatial data infrastructure. This will facilitate seamless data integration across the map sheets and administrative boundaries (RRSSC Nagpur 1995). The strength of the spatial data infrastructure mainly lies with the planimetric and thematic accuracy. The planimetric accuracy depends on the data used, datum, coordinate system and projection adopted for a given area (RRSSC Nagpur 1999). The projection to be adopted for a given area depends upon the location, size and shape (SAC 2001). The information generation is mainly carried forward from the village level through block, taluk, district and state, to the national level in India. Since the data has to be collated from various sources and scales, the projection parameters adopted for seamless data integration will vary considerably. A detailed estimation of the angular and linear distortions is a necessity to evaluate various map projections and arriving at a suitable map projection at state level for RS and GIS applications (SAC - Report on Datum and Map Projections for future IRS data products, Space Application Centre, Ahmedabad 2001). At present and in near future the availability of high spatial resolution satellite data help in generation of thematic maps at large scale ranging from 1:12,500 to 1:4,000. Integration of thematic maps at these scales will require precise coordinate system both at regional and local level. Therefore a novel solution of state plane

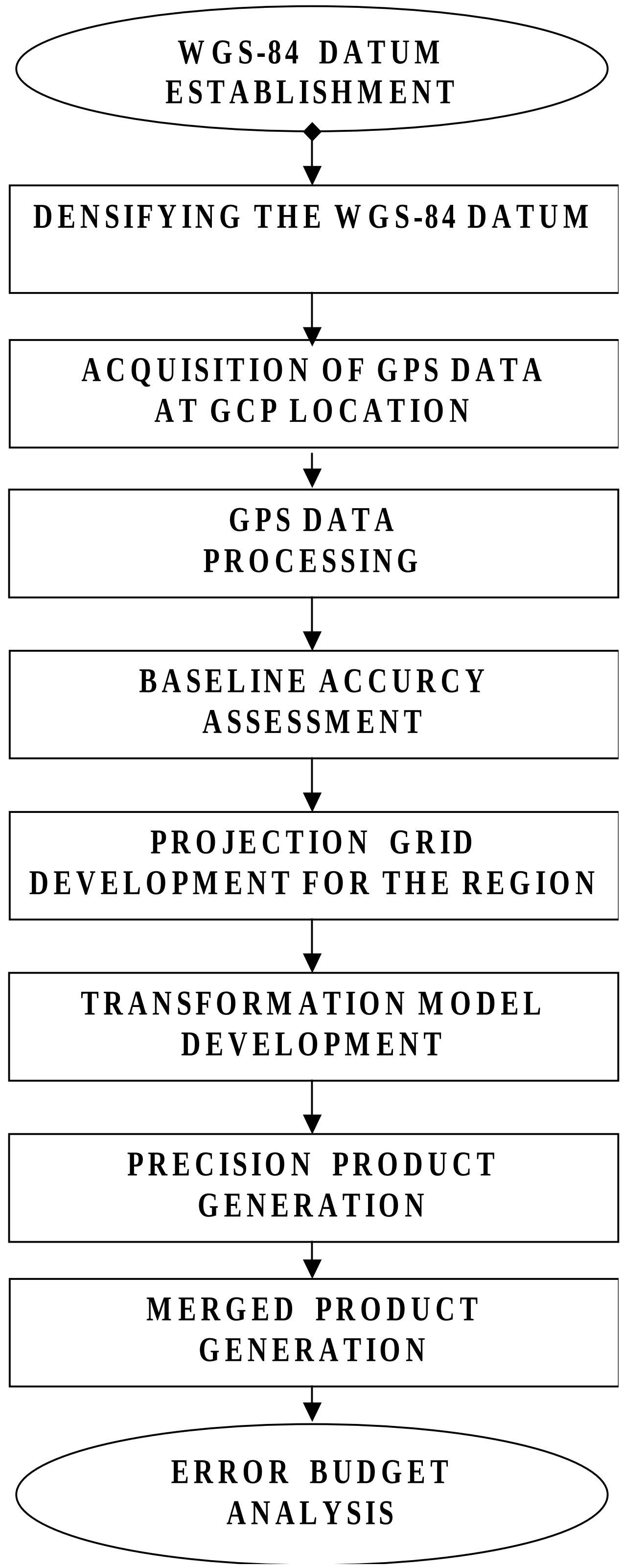

Figure 1. Methodology Flow Chart.

Table 1. Error budget analysis in generating precision products (in meters)

S.No	Parameter	Using Conventional (Map based) Ground Control Points	Using GPS based Ground Control Points
1	Inherent plotting accuracy	12.5	-
2	Image-map transformation error	15.0	-
3	Error in the tiling of reference maps	6.0	-
4	GPS receiver positioning at the GCP	-	2.0
5	Baseline accuracy	-	1.0
6	Image-GCP transformation error	-	12.0
	Total error in meters (Approximate)	**35 – 45**	**15 - 20**

coordinate system pertaining to Indian scenario, with projection accuracy threshold of 1 in 10,000 has been suggested (RRSSC Nagpur 2000). The state level coordinate system with LCC / Transverse Mercator projection is developed for each state. The satellite data will be geo-referenced using GPS based ground coordinates on WGS-84 datum and the basemap is extracted from the satellite data. The proposed concept is immensely helping the spatial data infrastructure for Indian scenario.

TRANSFORMATION MODEL DEVELOPMENT

The GPS based GCP coordinates, in latlongs, are converted into cartographic coordinates using the state level projection coordinates. A blank image file is created for the study area. The GCP coordinates and raw image coordinates are used to generate a GCP segment. This GCP segment is read as transformation model and depending upon the number of points, first order or second order transformation model is established. Check for the residual error at each point and rms error for the model. Residual error and rms error should not exceed 6.25 meters. If the error exceeds the limits, adjust the model or densify the GCP's.

PRECISION PRODUCT GENERATION

Based on the transformation model, each satellite data is geo-referenced. As explained above, based on the number of GCP collected within the area of one LISS III scene, either LISS III (Less number of GCP) or PAN (More number of GCP) data is rectified. In the first case, the PAN data is registered using the geo-referenced LISS III data as the reference image. Both the rectified images are overlaid one over the other to check for co-registration. If the matching is perfect, proceed for merging of the dataset.

MERGED PRODUCT GENERATION

The registered PAN and LISS III data are fused using HSI transformation technique. Before applying the fusing technique, the PAN data can be sharpened to generate edge-enhanced product (Lillesand & Keifer 1987). The High Resolution Edge Enhanced Colour Composite (HREECC) thus generated form as the basic image for capturing the topographical information (RRSSC Nagpur 2000). The output is compatible for 1:25,000 scale mapping. According to the survey procedures, the scale of the base image should be double the scale of mapping. Hence, for the 1:50,000 scale mapping, the merged product is generated with 6meter spatial resolution that characterizes better than 1:25,000 scale images.

CONVENTIONAL (MAP BASED) GROUND CONTROL POINT ACQUISITION

The topographical maps represent the ground features at a particular scale. The coordinates of the ground control points can be measured directly on the ground using surveying techniques or can be derived from the topographical maps. The topographical maps, generated with high accuracy, are used for deriving the coordinates of the GCP's for geo-referencing the satellite data. The steps involved are

- Scanning of topographical maps, within the purview of map restriction policy
- Tiling of the scanned maps
- Image to Map transformation model
- Precision product generation

The maps are scanned with 100 DPI. The scanned product will carry forward the inherent errors in the map sheet and the scanning errors. The scanned maps are tiled to a defined grid to generate a mosaic of topographical pertaining to the study area. The satellite images are registered by developing a transformation model between the map mosaic and the satellite image. Through this model, the image rectified.

All the process induces certain quantities of error which reduce the locational accuracy of the rectified images. The reference maps are generated with plotting error of 12.5 meters. The maps are tiled with root mean square error of half a pixel (equivalent to 6.00 meters) at an average. The satellite data is registered with rms error of around half a pixel value (equivalent to 13 to 15 meters). The total error budget is of the order of 35 to 45 meters.

After GPS technology was evolved the positioning of points has become very precise (Gunter Seeber 1993). The GPS can provide sub-metre accuracy in point positioning, in differential mode (Smith D P and Atkinson S F, 2001). An attempt is made to rectify the satellite data and analyze the error budget with both the approaches.

ERROR BUDGET ANALYSIS

The errors involved in this process of generating precision products are given below.

- GPS receiver positioning at the GCP (Post Pointing error)
- Baseline accuracy
- Image-GCP transformation error

In the study, the IRS 1C LISS III data with a spatial resolution of 24 m and PAN data with 6 m resolution are used to generate precision products compatible to 1:50,000 scale mapping. The error budget calculated in the study is presented in Table 1.

Advantages of GPS based GCPs: From the error budget analysis, it is clear that using GPS based GCPs enable generation of precision products with plannimetric accuracy around 15 -20 meters, where as the conventional (map based) method produced an accuracy of 35 - 45 meters. The GPS technology has emerged as powerful tool in point positioning and is readily adopted in image processing & GIS techniques for generating value added products.

However, the cost component has to be kept in mind while using GPS technology. The map-based methods are very economical where as the GPS method will incur the financial resources for data collection and processing. The cost factor can be overcome by considering large areas of the order of 20,000 sq.km. equivalent to the one LISS III scene.

RESULTS & DISCUSSION

By using GPS based ground control points, the locational accuracy of the satellite data has increased from 35-45 meters to 15-20 meters. The cartographic potential of a satellite depends upon the locational accuracy in addition to the spatial, radiometric and spectral resolutions. The improved locational accuracy will enhance the cartographic potential of the satellite data. The mapping organisations can adopt this approach in generating the conventional maps using satellite data and GPS.

CONCLUSIONS

The results are clearly demonstrating the potential of satellite data and GPS for generating the valuable inputs for making the cartographic maps. The very high-resolution RS data, i.e. IKONOS and CARTOSAT, with the help of GPS based GCP's, will revolutionize the mapping concepts.

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