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GCP COLLECTION FOR CORONA SATELLITE PHOTOGRAPHS: ISSUES AND METHODOLOGY

AJAY DASHORA, B. SREENIVAS, BHARAT LOHANI[@],
JAVED N. MALIK AND AFROZ AHMAD SHAH
Department of Civil Engineering,
Indian Institute of Technology Kanpur, Kanpur-208016, India
[@]Corresponding author: blohani@iitk.ac.in

ABSTRACT

Use of high-resolution and historic CORONA satellite photographs for mapping and other purposes requires Ground Control Points (GCPs), as ephemeris data and image parameters are not available. However, the alterations in landscape in last 34 years (*i.e.*, since the acquisition of these photographs) prevent identification and collection of large number of GCPs in the field. This paper presents a methodology for collection of GCPs for CORONA photographs. The advantages and limitations of the methodology are discussed. For a study site, situated in Siwaliks and Lower Himalayas, the GCPs were identified in CORONA photographs and their WGS84 coordinates were estimated through a process of datum transformation and georeferencing. Estimated GCP coordinates from the topo sheets and 2D and 3D views of photographs, helped in identifying the GCP locations in field, which were observed using DGPS. Investigations were carried out to relate Differential Global Positioning System (DGPS) accuracy with base line length and time of observation. A base line of 350 km and half an hour observation were found appropriate to yield accuracy in GCP collection by DGPS method, which conforms to CORONA resolution of 3 m.

Introduction

CORONA is the first successful space reconnaissance program during 1960 to 1972. During those twelve years, it acquired information from Earth's surface by collecting numerous images. Out of 105 total missions, 95 were successful. The CORONA satellite used a set of panoramic cameras with KH (Key Hole) designations. Panoramic cameras captured the images on a photographic film of size 757 mm by 55 mm, by scanning through 70°. CORONA KH-4A and 4B camera systems were

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employed with two panoramic cameras to ensure stereoscopic vision. CORONA images were declassified in 1995; the latest available CORONA imagery is 32 years old. CORONA images are cheaper than other available remote sensing data. A direct comparison shows that CORONA images are made available at a reasonable price (1 cent per km^2) compared to IKONOS (US \$ 29 per km^2) and SPIN-2 (US \$ 35 per km^2). On the contrary, CORONA KH-4B images have good resolution (1.83 m) (Altmaier and Kany, 2002).

CORONA images suffer with severe generalized distortions, mainly imparted by panoramic geometry and dynamic imaging system (Shin, 2003). Further, the ephemeris data and image parameters are not available. Therefore, in order to use these photographs for mapping purposes it is required to develop mathematical models, which are based on GCPs. These rectification and modelling procedures require GCPs of accuracy more than half the spatial resolution of image. However, the changes in landscape that occurred in last 34 years restrict the collection of GCPs. This paper discusses the technical aspects of a methodology, and its implementation steps for GCP collection for CORONA photographs.

Methodology

Ideal GCPs are characterized by intersection of features, such as roads, canals or streams (Lillesand *et al.*, 2003). Considering the high-resolution of CORONA photographs, GCP collection by Global Positioning System (GPS) is preferred, particularly in view of the non-availability of large scale maps.

The GCPs with desired accuracy are obtained using the following steps:

- Scanning of CORONA photographs,
- Identification of appropriate GCPs and estimation of their approximate coordinates in WGS 84,
- Decision on duration of GPS observation and baseline length for performing DGPS in field with the desired accuracy,
- GPS field survey for GCPs collection, and
- GPS data processing for validation for GCPs.

Fig. 1 shows details of approach.

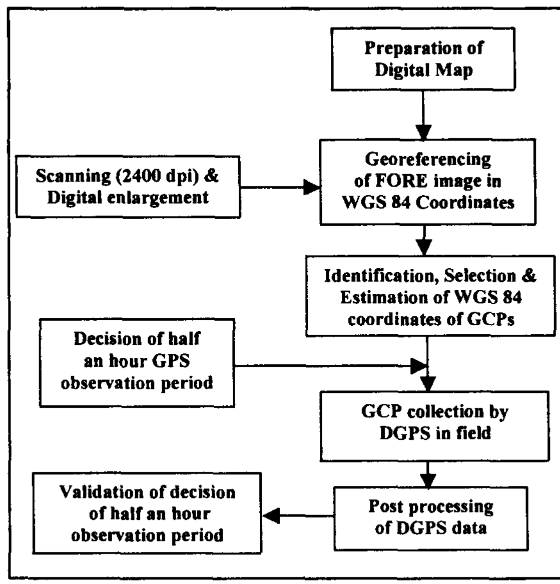

Fig. 1. Flow chart showing the methodology.

Study Area, Image Data and Topo Sheets

The selected study area, covering longitude from 79° 0′ 0″ E to 79° 20′ 30″ E and latitude from 29° 30′ 0″ N and 29° 20′ 0″ N on Everest spheroid system, is situated in the hills of Shivaliks and Lower Himalayas near Ramnagar, in Nainital district of Uttaranchal state of India. The study area corresponds to Survey of India map sheets 53-O/3 and 53-O/7. The study area mentioned, consists of all kind of natural and man made features like hills, planes, forest, rivers, villages, small streams, canals, and developed area (Fig. 2).

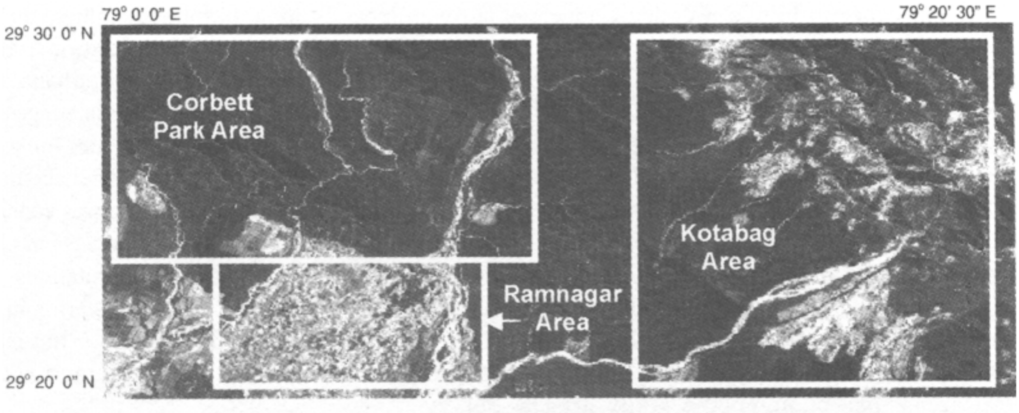

Fig. 2. The study site (52, Forward image).

The whole study area can be broadly divided into two sub areas namely Ramnagar and Kotabag. Ramnagar, situated at the western bank of Kosi River, consists of urban area, villages and Corbett National Park. In this area, point bars, rivers with broad spans but narrow and shallow water streams are common natural features. The whole Kotabag is mainly dominated by highly undulating terrain with steep slopes, covered by trees of Teak, Sal and Pine.

The study area is covered in CORONA photographs numbered, 52 forward and 58 aft of mission 1112-1 (Fig. 2). These images, captured on November 24, 1970, correspond to CORONA KH-4B camera (McDonald, 1995). The study area covered 114.30 mm (4.5 inch) length on both forward and aft image strips, therefore occupying 15% of total area of a strip. Further, the maximum area covered by an image strip is 217.00 × 16.00 km^2 (Sohn *et al.*, 2004), which determines the dimension of study area as 32.77 × 16.00 km^2. Also, both aft and forward images are from middle portion of the CORONA photograph strip with approximately 80 % overlap between them.

Planning and Scanning

Planning involved identification of GCPs on scanned image of study area. An attempt was made to determine the approximate coordinates of identified GCPs in WGS84 system to use these coordinates in the field for locating GCPs using GPS.

CORONA films were scanned for digital processing. Leachtenaver *et al.* (1998) performed a study on the effect of scanning resolution vs. interpretability of images and found that lossless digitization of CORONA photogarphs requires a scanning resolution of 4 μm. Moreover, information content of scanned image does not depend on type of scanner. In the present case, the CORONA film negatives were, however, scanned at 2400 dpi (10.58 μm) by a flatbed scanner, as it was the best available scanner. Scanning determines the average ground resolution of 3.04 m (Dashora, 2005). Utmost care was taken to hold the film negatives by using dry cotton gloves because scratches and finger prints could degrade the information content of image.

Digital enlargement, GCP identification, and estimation of coordinates of GCPs in WGS84 using ERDAS Imagine software

The intersections of features like roads, railway lines, canals and streams were marked as GCP locations. During GCP identification, shortest and feasible path to reach a GCP were determined using map sheets. Map sheets revealed several facts like type of a bridge (concrete bridge, wooden bridge, suspension bridge or causeway) over intersections of roads with streams and canals. This ancillary information about the GCP location helps in locating the GCP with higher confidence. Linear features like roads, canals and major rivers were followed to reach a GCP, as these divide the large area into two smaller parts and establish the correlation between GCP location in image and map sheets. About 170 GCPs were marked both in image and map sheets in laboratory. Rapid growth of population and infrastructure, especially of road networks and residential areas, has changed the study area substantially since the acquisition of images, as anticipated.

To get help in locating the marked GCPs (on image) on the ground their WGS84 coordinates were determined. For this the topo sheets were scanned and georeferenced in WGS84 coordinate system using four well defined points. The WGS84 coordinates of these points were determined by converting the Everest spheroid coordinates into WGS84 coordinates using transformation function of software ERDAS Imagine. The complete digital map was prepared by mosaicking the individual maps. The CORONA image was georeferenced in WGS84 by second order transformation using eleven uniformly distributed GCPs in digital map. The approximate WGS84 coordinates of GCP locations were thus known and recorded. The accuracy of this procedure is expected to be lower in view of the use of global transformation parameters employed by ERDAS. However, the aim of this procedure is only to have an estimate, which could be helpful while working in field.

Decision for GPS observation period and length of baseline

The average ground resolution (3.04 m) of image was taken into account to decide the Differential GPS (DGPS) base length and observation period for rover. The observation time at rover depends upon: baseline length, availability of satellites at the time of observation, satellite geometry (GDOP) and ionosphere disturbances. Two to three hours observation at rover is suggested to obtain millimetre accuracy for baselines longer than 30 km (Leica, 2000). A decimetre level accuracy of reference data for image rectification was considered acceptable for a 3.04 m resolution images in present case. Further, considering the field limitations, it was not desirable to set up the reference station in field. The reference station of IITK which is around 350 km from study site was desired to be used in DGPS survey.

A study was performed to examine the effect of baseline length and time of observation on the coordinates of a rover. For this, the coordinates of 6 points in the campus of Indian Institute of Technology Kanpur (IITK) were determined by DGPS survey with respect to two reference stations, *i.e.*, at IITK and at Indian Institute of Science Banglore (IISB). The IITK station was established accurately by a long period of observation (Sreenivas, 2003). The observations were taken for half an hour duration. The coordinates of 6 points computed with reference to IITK station can be considered accurate as per Leica (2000), for 1 km baseline length and 30 minutes observation. It was observed that the difference between the corresponding coordinates of a point, obtained by DGPS with these reference stations (base lengths of order of 1 km and 1500 km, respectively), were between 60-90 cm in X, Y, and Z. On the basis of this, it was concluded that the half an hour observation at rover (GCP location) would be sufficient to obtain desired accuracy over a base line of 350 km (*i.e.*, aerial distance between Kanpur and the study site). This decision, however, was validated after field survey and is discussed later.

GPS Observations of GCPs

Field survey for GPS data collection by Differential GPS (using Leica SR530) was started on

October 23, 2004 and continued for 25 days. Local guides provided important information to reach remote GCPs. 3D views using pocket stereoscope were employed for planning the field work. A GCP location was confirmed by visual observation of its surroundings, resection with the surrounding objects using a magnetic compass, map sheets, and WGS84 coordinates estimated in laboratory. Estimated coordinates of GCPs in laboratory helped in reaching the area of the GCP and avoided getting lost in the field. DGPS observation for half an hour was taken for GDOP less than 8 and at least five satellites above cut off angle of 15°. Observations were also assigned weights, according to confidence of occupying a GCP marked on image on to the ground through manual judgment. In addition, consulting with local guides and forest officials revealed the alterations in study site over last 34 years. For example, damages of older roads, encroachment of older roads, blocking of a road owing to administrative decisions, erosive nature and extent of erosion by river every year, suspected areas for wild life, outdated village paths due to highway construction, shifting of old forest boundaries, and changes in geomorphology, *etc.* Narrow road bridges over small streams, though good GCPs, proved difficult for observation due to heavy traffic. Dense forest canopy did not allow GPS to work. Sometimes, due to improper geometry of satellites, GDOP value degraded and reached below 20. This increased the observation period.

It was observed in field that structures of public interest and religious significance like canals, temples, mosques, and old monuments remained intact since imaging. Linear features and ancillary information helped in quickly accessing the GCP location. New GCPs were also identified and collected with the help of already identified GCPs. Many GCPs selected in laboratory could not be located due to changes in landscape. A total of 75 GCPs were finally collected. Out of these, 50 were already marked in image and 25 were selected at site.

Post Processing of GPS Data

Data processing for field data

GPS data of reference and rover stations were processed in DGPS mode. First, the precise coordinates of reference (base) station at IITK were determined by processing the GPS data of base station at IITK for 24 days with respect to IISB base station. The station at IITK was then used as reference station for field GPS data processing. The data were longitude, latitude, ellipsoidal height, UTM easting and UTM northing in WGS 84 coordinates system for all GCPs collected in field. The differences between the estimated-in-laboratory and measured-in-field WGS 84 coordinates both in latitudes and longitudes, for 50 GCPs were determined. After removing the outliers, differences for 46 points (Table 1) were plotted as shown in Fig. 3. Observed coordinates show a shift from estimated ones in the North West direction. However, no quantitative examination was carried out to check for their pattern. These results indicate that estimated-in-laboratory coordinates could be useful, though should be used with care.

Table 1: Statistics of differences in coordinates of estimated-in-laboratory and measured- in-field for 46 points

	Difference in Latitude (m)	Difference in Longitude (m)
Mean	166.711	103.917
Minimum	-200.847	-203.775
Maximum	351.565	361.607
Std. Dev.	96.390	120.302

Validation of half an hour GPS observation period by accuracy analysis

Further study was performed to examine the quantitative effect of half an hour observation period on accuracy of a GCP, over a long base line. The precise WGS 84 coordinates of the reference station

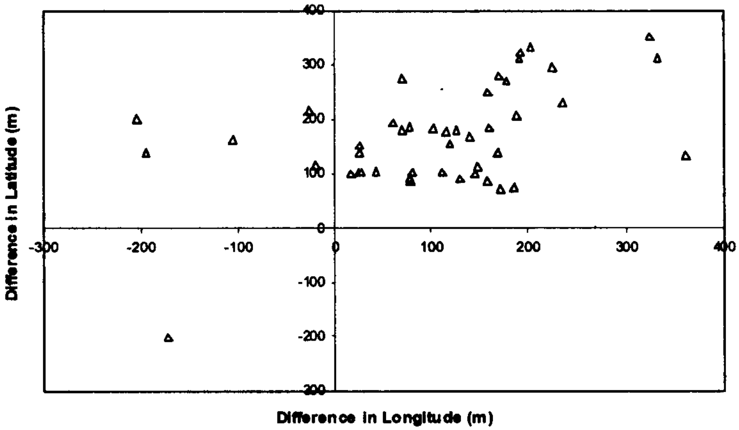

Fig. 3. Difference of estimated-in-laboratory and measured-in-field coordinates for 46 points.

at IITK were determined using 24 days data of IISB as:

Longitude: 80° 13′ 54.31″ E; UTM Easting: 423451.1639 m;

Latitude: 26° 30′ 46.07″ N; UTM Northing: 2932704.0132 m;

Ellipsoidal Height: 76.6589 m

From the available 24 days data a total of 73 random samples, each of half an hour duration, were chosen. Each sample represented half an hour observation at the reference station of IITK. All the 73 sample data were processed with respect to IGS station at IISc Banglore as base station and then WGS 84 coordinates of IITK reference station were determined. The difference of these coordinates and the precise coordinates (shown above) were calculated for all parameters, namely latitude, longitude, height, UTM easting and UTM northing. These differences were reported as errors. For 73 samples, the error statistics was generated for all parameters. These errors were plotted for latitudes, longitude and ellipsoidal height (Fig. 4). Table 2 shows the error statistics in coordinates of reference station at IITK due to half an hour observation for a baseline of around 1520 km. The mean, minimum and maximum values of errors in easting and northing are less than the half of ground pixel resolution (1.5 m) of image. Therefore, it was concluded that the half an hour observation over a baseline of 350 km is good enough to provide the coordinates of GCPs, as required for rectifying an image of 3.04 m resolution.

Table 2: Precision of coordinates of IITK reference station estimated from 30 minute GPS observation for 73 samples

	Error in UTM Easting (m)	Error in UTM Northing (m)	Error in Latitude (deg)	Error in Longitude (deg)	Error in Ellipsoidal Height (m)
Mean	0.09759	0.09107	6.6567E-07	1.71817E-06	-0.2309
Minimum	-0.9408	-0.4634	-1.186E-05	-8.705E-06	-1.0855
Maximum	1.2316	0.478	4.3522E-06	1.3095E-05	0.784
Std. Dev.	0.46919	0.14651	1.9894E-06	4.70913E-06	0.38026

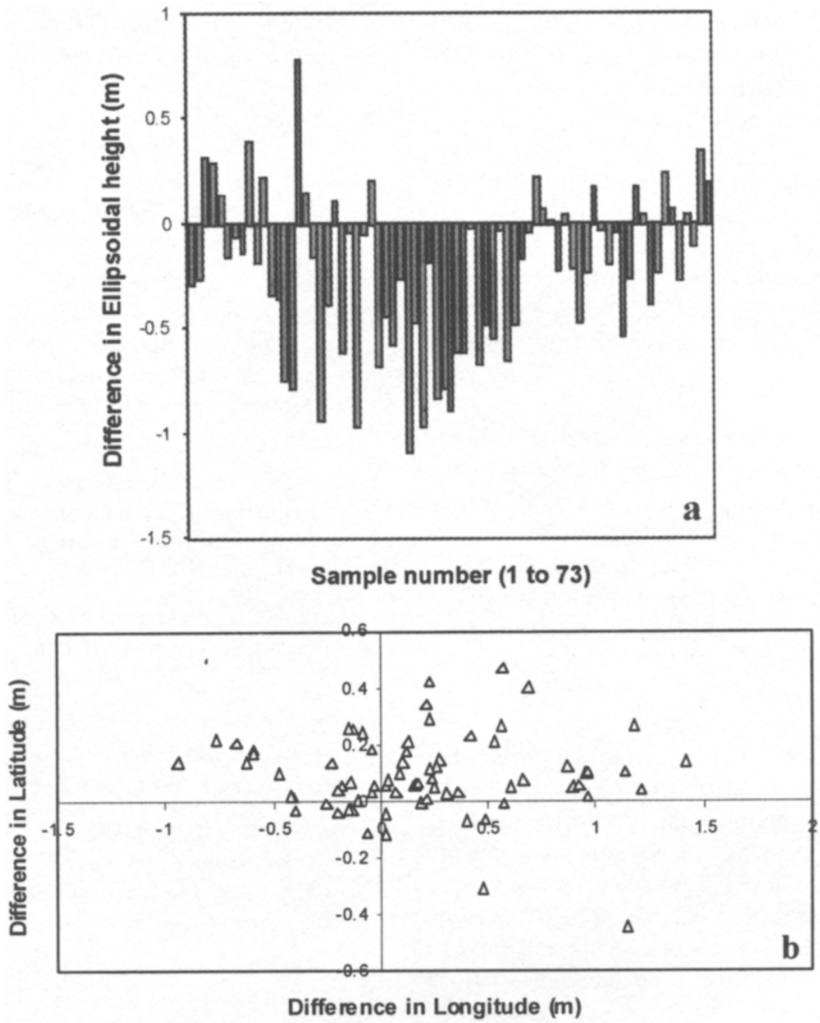

Fig. 4. Error in coordinates of IITK reference station estimated from 30 minute GPS observation for 73 samples: 4(a) Ellipsoidal height; 4(b) Latitude and Longitude.

Discussion and Recommendations

Numerous precautions were taken to collect GCPs, yet some shortcomings were also observed. The recommendation given in the following paragraph, along with the strategy discussed above, may be beneficial for researchers interested in this kind of study.

Scanning at digitizing resolution of 4 μm will improve the interpretability of image. Extraction of networks of roads, canals and streams and their intersections using the radiometric and spatial enhancement operations should provide detection of more GCPs. Moreover, registering the CORONA photographs with the latest high resolution image of study area may help in locating the GCPs with their relationship to the present landscape. 3D views of area using either a stereoscope or on-screen stereo, facilitates GCP selection at planning stage and also while working in field.

Composing the images in a poster form (A0 size; 44 by 36 inch) would avoid carrying unnecessary number of sheets in field. In the field or at the end of survey work every day, a portable computer would be useful to process and verify GPS data. Therefore, data with poorer accuracy may be rejected in field.

GCP locations surrounded by the trees should be observed using the auxiliary instruments that measure the distance and bearing at a GCP location and transfer this data to the GPS instrument, set under the open sky, in real time mode. Thus, coordinates of a point, under dense forest canopy, can be determined in WGS84 coordinate system.

Conclusion

The present results provide details of a methodology for collecting GCPs for CORONA photographs, which otherwise is a difficult process in view of the changes in landscape since capture of these images. Further, it is shown that the desired GCP accuracy of half pixel size can be obtained by DGPS survey with a longer baseline (≈ 350 km) and half an hour observation. The recommendations made in this paper and the strategy adopted can be useful for users who aim at collecting GCPs for CORONA or other historical remotely sensed data. Finally, in order to confirm the results of this study, particularly about obtainable DGPS accuracy for half an hour observation over a long baseline, more experiments are desired.

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