Comparative evaluation of Cartosat-1 and SRTM imageries for digital elevation modelling

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(Received 9 February 2012; final version received 12 May 2012)

Digital Elevation Models (DEM) of a hilly-valley region are prepared using stereo images of Cartosat-1 and Shuttle Radar Topography Mission (SRTM) images. The procedure of ortho-image generation from Cartosat-1 stereo images and the estimation of ground features from ortho-image are elaborated in the paper. Comparison of DEMs prepared from both images is discussed in terms of the quality of ground features detection, hydrological applications and geometrical calculations. It is found that DEM prepared from Cartosat-1 images are more accurate in the valley region and hence it is better suited for hydrological applications. On the contrary, for hilly region, SRTM images produce better DEM. However, if ground control points and Rational Polynomial Coefficients can be obtained in the hilly region, more accurate DEM can be prepared using Cartosat-1 stereo images.

Keywords: digital elevation model; Cartosat-1; SRTM

1. Introduction

Using remote sensing techniques, a Digital Elevation Model (DEM) is generated from Cartosat-1 stereo images and Shuttle Radar Topography Mission (SRTM) images. Due to high resolution of Cartosat-1 images, in general, the developed DEM is more accurate as compared to DEM developed by STRM. This paper investigates the accuracy of DEM prepared by these two image formats and suggests the application areas where Cartosat-1 and SRTM can be used successfully. Cartosat-1 launched by ISRO in May 2005 provides seven levels of data products acquired by the two state-of-the-art panchromatic cameras that take black-and-white stereoscopic pictures with a spatial resolution of 2.5 m in the visible region of the electromagnetic spectrum. The cameras cover a swath of 30 km and are mounted in such a way that near simultaneous imaging of the same area from two different angles is possible. This facilitates the generation of three-dimensional digital maps of an area. These latest features in the imageries have opened up advanced applications of Cartosat-1 data in mapping urban areas and updating the topographic maps for various features like local roads, crop field boundaries, small ponds, play grounds, swimming pools, parks, hydrological features like flow length, flow accumulation and stream network, for observing terrain conditions like slope and aspect etc. The Cartosat-1 stereo pair data along with the Rational Polynomial Coefficients (RPCs) are used to generate DEM.

The SRTM was launched in collaboration with National Geospatial-Intelligence Agency. The SRTM collects interferometric radar data which has been used by Jet Propulsion Laboratory to generate a near global topography data product for latitudes smaller than 60° (1). SRTM is the first space-born single pass interferometric Synthetic Aperture Radar (SAR) which produces high resolution, digital elevation maps. The SRTM system included the spaceborne imaging radar-C (SIR-C) and X-band Synthetic Aperture Radar (X-SAR) systems that had flown twice previously on other space shuttle missions (2). For this study, the Cartosat-1 and SRTM images of an area covering approximately 625 km² lying in a part of Jharkhand state are obtained from National Remote Sensing Centre (NRSC) and U.S. Geological Survey/Global Land Cover Facility, respectively, as shown in Table 1. Using stereo images of Cartosat-1 and SRTM images, DEM are developed and these DEMs are compared with toposheet and field measured data for the different applications such as, feature detection, hydrological studies, volume calculation and others.

From now onwards, the DEM prepared from Cartosat-1 and SRTM images will be designated as DEM-CART and DEM-SRTM, respectively.

2. DEM and ortho-image generation using Cartosat-1 stereo images

A DEM is a digital representation of ground surface topography or terrain. Digital elevation data can be grouped into four basic approaches: grid, contour, profiles and triangulated irregular network (TIN) (3). DEMs
are created by (i) field surveying, (ii) digitising hard copy contour maps or (iii) photogrammetric analysis of stereo aerial photographs or satellite stereo images (4,5). An important aspect in DEM is to generate ortho-images for subsequent analysis of the model.

Ortho image is an image that shows ground objects in their true map or so called orthographic projection (6). An orthographic projection is the one in which the projecting rays are perpendicular to the plane of projections. The digital terrain profiles generated in the ortho-photo production process comprise a DEM of the terrain covered by the ortho-photo. Ortho-rectification is a process of correcting the imagery into a planar, map-like form by accurately removing all sensor, camera and terrain related distortions based on camera/sensor models, terrain models and ground control points. The procedure for making ortho-images are (i) interior orientation, (ii) exterior orientation, (iii) tie point generation, (iv) triangulation, (v) model refining using GCPs and (vi) DEM generation. In this study, all the above operations are performed on Cartosat-1 images using Leica Photogrammetric Suite (LPS) version 9.1.

One of the most important steps in DEM modelling is to generate tie points from the stereo images. A tie point signifies a point having unknown ground coordinates, but easily recognisable in the overlap area between two or more images. The corresponding image positions of tie points appearing on the overlap areas of multiple images are identified and measured. Ground coordinates for tie points are computed during block triangulation. To develop an accurate DEM, tie points should be visually well-defined in both the images. The information of each scene is contained in several files as mentioned in Table 2. As for example, BAND-A and BAND-F are image files and “.rrd, .aux and .txt” files are supporting files, provided by NRSC, Hyderabad. Tie points must also be well distributed over an area of the block and uniform distribution of tie points plays significant role in accuracy assessment (7). Typically, nine tie points in each image are adequate for block triangulation (8). The LPS automatically generates the tie points between the images in their overlap region. Manually, more tie points can be added for even distribution throughout the image overlap region. For this study, a total of 27 tie points are used for each pair of images. These tie points are visually checked, using survey of India (SOI), toposheets of the study area for their location accuracy. The distribution of the tie points is shown in Figure 1.

Other than tie points, ground control points (GCPs) are also required for triangulation. Triangulation is a process of establishing a mathematical relationship between the images, sensor model and the ground. The information resulting from triangulation is fed as input for the ortho-rectification process. For this study, 13 GCPs are added and triangulation is performed to check the model accuracies at all the tie points. An average RMSE of 2.3 pixels is achieved for image rectification.

### Table 1. Product details of the images.

| Details          | Cartosat-1          | SRTM       |
|------------------|---------------------|------------|
| Path – Row       | 578–292             | 156–265 (ID)|
| Date of pass     | 12th December 2006  | February 2000 |
| No. of bands     | 1                   | 1          |
| Undulation (m)   | 110 – 420           | 110–430    |
| Pixel resolution | 25                  | 90         |
| Latitude         | 22°36'58.61N to 22°53'00.65N | 22°36'58.61N to 22°53'00.65N |
| Longitude        | 85°56'38.99E to 86°11'56.18E | 85°56'38.99E to 86°11'56.18E |

### Table 2. Detail information of the stereo pair.

| Stereo Pair     | Image 1     | Image 2     | Format |
|-----------------|-------------|-------------|--------|
| BAND-A          | BAND-F      | TIFF        |
| BAND-A_RPC      | BAND-F_RPC  | .txt        |
| BAND-A          | BAND-F      | .rrd        |
| BAND-A          | BAND-F      | .aux        |
| BAND-A_MET      | BAND-F_MET  | .txt        |
| BAND-A_RPC_ORG  | BAND-F_RPC_ORG | .txt        |

Figure 1. Tie point distribution in the stereo pair.
elevations (6). The ground control points having latitude, longitude and elevation information are fed into the software and the corresponding image points are identified in the BAND-A and BAND-F images. The image chips and the ground photos of the area corresponding to GCP points are referred as the identification of image points in the Cartosat image (9). However, more accurate GCPs can be generated by DGPS survey of the area. Due to the unavailability of the DGPS and undulating nature of the ground, this survey is not conducted and hence SOI toposheets are used in this study for selecting GCPs. For this purpose, the SOI toposheet no. 73-J1 is used. The projection system and datum of this analysis is UTM and WGS84 respectively. The distribution of the control points and check points is shown in Figure 2. The inclusion of GCPs has improved the planimetric accuracy from 100–250 m to 5–15 m.

2.2. Dem generation and ortho-image generation
Figure 3 depicts the resulted DEM developed from the Cartosat-1 stereo images. Figure 4 shows the ortho-rectified Cartosat-1 image of the study area. From Figure 3, it is found that the minimum and maximum elevation of the ground is 110 and 420 m respectively (above mean sea level). Black colour indicates the hill area and white colour indicates the low-lying area. Figure 4 clearly shows the national highway, the Subernarekha River and its tributaries, railway lines, houses, fields and others features. DEM of the same area is also prepared form SRTM images using ERDAS Imagine 8.5 as shown in Figure 5. The white colour in the figure indicates the hill area and black colour signifies the low-lying area. Due to the low resolution (90 m) of SRTM-DEM, although the Subernarekha River and Kharkai River are clearly seen in the SRTM image, their tributaries are not clearly visible, but due to the high resolution (25 m) of CART-DEM, tributaries are distinctly identified in the Cartosat-1 image.

3. Comparative assessment of the spatial accuracy
The spatial accuracy of DEM-CART and DEM-SRTM with reference to the SOI Toposheet is determined for 40 data points randomly selected from the study area. Figures 6 and 7 respectively show the longitude and latitude of those points obtained from Cartosat-1, SRTM and Toposheet. It is clear that spatial accuracy of both DEM-CART and DEM-SRTM are extremely high as compared to Toposheet Longitude–Latitude values.

4. Comparative assessment of the quality of DEMs
From the DEM-CART and DEM-SRTM, 10 m contour interval elevation maps are prepared and compared
Figure 4. Ortho rectified Cartosat-1 image near Subernarekha River.

Figure 5. Digital elevation model of SRTM.

Figure 6. Longitude of Cartosat-1, SRTM and toposheet.
with those of toposheet no. 73-J1. Altogether, 234 points are randomly taken for comparison as shown in Figure 8. The elevation values of points are marked in Figure 8. The elevations obtained from DEM-CART, DEM-SRTM and of toposheet are shown in Figure 9. The absolute error (m) in elevation between DEM-CART and toposheet, DEM-SRTM and toposheet is plotted as histogram (Figure 10). From both the figures, it is clear that elevations estimated from DEM-CART are more close to toposheet elevations as compared to DEM-SRTM. Table 3 lists the statistical errors of estimation and corroborates that DEM-CART provides better estimation of surface topography as compared to DEM-SRTM.

![Figure 7. Latitude of Cartosat-1, SRTM and toposheet.](image)

![Figure 8. Random selection of elevation points overlaid with Cartosat-1 DEM.](image)

![Figure 9. Scatter plot SRTM and Cartosat-1 elevation values w.r.to toposheet.](image)

![Figure 10. Histogram error plot of SRTM and Cartosat-1.](image)

DEM-CART are more close to toposheet elevations as compared to DEM-SRTM. Table 3 lists the statistical errors of estimation and corroborates that DEM-CART provides better estimation of surface topography as compared to DEM-SRTM.

From the Figure 10 in the case of DEM-CART, the absolute error was zero in 186 places, the absolute error
was “−5” in three places and the absolute error was “−10” in four places only, while in the case of DEM-SRTM it is only 88, 80 and 58 places respectively.

5. Some applications of DEMs

5.1. Estimation of river profiles

Profiles (cross section) of Subernarekha River were collected at Adityapur and Jamshedpur by Central Water Commission. The profile data collected are measured on 21 May 2005 at Adityapur and is on 22 November 2005 at Jamshedpur. At the same location, profiles of the river are generated from DEM-CART and DEM-SRTM. Figures 11 and 12 show the comparative river profiles and it can be seen that river profiles generated from DEM-CART are closely related to the measured profiles. The minimum absolute error of DEM-CART in the middle of the river is found to be about 3 m at Jamshedpur and 0.09 m at Adityapur, this error increases to 4 m at Jamshedpur and 4.45 m at Adityapur respectively for DEM-SRTM. Hence, for water resources applications such as flood forecasting and inundation studies, Cartosat-1 imageries will be more appropriate.

5.2. Calculation of volume of hill regions

In order to compare the efficiency of DEMs developed using DEM-CART and DEM-SRTM, the volume around a hill area was calculated and verified by digitising contours of the toposheet. A TIN map of the hills was generated using digitised contours of toposheet as shown in

![Figure 11. Comparison of river profiles at Jamshedpur station.](image)

![Figure 12. Comparison of river profiles at Adityapur station.](image)

![Figure 13. Extraction of hill profile from the TIN plot.](image)
Figure 13. The maximum and minimum elevations of the hill in DEM-CART are 260 and 150 m respectively, and the volume is 141.3 km$^3$ calculated from the base of the datum. The maximum and minimum elevations of the same hill in DEM-SRTM are found to be 310 and 150 m respectively, and the volume is 248.5 km$^3$. This maximum and minimum elevations of the hill in the toposheet are measured as 327 and 150 m respectively and the volume of the hill is estimated to be 260.2 km$^3$ (Table 4). Figure 14 shows the comparison in elevation among DEM-CART, DEM-SRTM and toposheet. The maximum elevation and volume of hill of DEM-SRTM are closely adhered to toposheet. From this study, it is clear that due to the unavailability of RPCs and GCPs in the hill region, the DEM-CART is not accurate for that region.

6. Conclusion

Digital elevation models were prepared using stereo images of Cartosat-1 and image of SRTM. It was clearly shown that accuracy of DEM-CART will be higher if proper RPCs and GCPs are obtained. In general, RPCs are provided with the images and GCPs are generated from DGPS or toposheets. It may be noted that in the hilly region, it becomes difficult to do survey with DGPS. Hence in the absence of proper RPCs, interpolation of elevation in the hilly region (sharp slopes) becomes very difficult and thus, elevation values differ from ground truth measurements.

This study reveals that in the valley region (river profile estimation), DEM-CART produces more accurate elevations as compared to DEM-SRTM. The main reasons are (i) Cartosat-1 images are of high resolution and (ii) Sufficient number of RPCs and GCPs could be obtained. For hydrological, administrative, governmental and forestry applications, Cartosat-1 data are more appropriate and could produce ortho-image with high resolution of ground features.

Acknowledgements

The authors acknowledge Board of Research in Nuclear Sciences (BRNS), Bhabha Atomic Research Centre (BARC), Mumbai for sponsoring this project.

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