COMPARISON OF DEMS DERIVED FROM INSAR AND OPTICAL STEREO TECHNIQUES

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ABSTRACT

Optical stereo and Interferometric Synthetic Aperture Radar (InSAR) techniques were used to process the IRS-1C PAN stereo and ERS-1&2 tandem data respectively over Koyna and Mumbai test sites for digital elevation model (DEM) generation. For processing the data sets of optical stereo and InSAR, PCI OrthoEngine and Gamma softwares were used respectively. Heights from Survey of India topomaps (SOI) and GPS were used as ground control points in the process of DEM generation. A comparison was made between the DEMs of optical stereo and InSAR. It is observed that RMS error in the estimation of height of GCPs are 20 m and 9 m using optical stereo and InSAR respectively for Koyna test site. The same for Mumbai test site are 11 m and 16 m for the two techniques. By selecting random points from SOI maps, the RMS errors for koyna test site are 16 m and 30 m in height for optical stereo and InSAR respectively. The same for Mumbai test site using GPS data are 10 m and 13 m respectively. The DEMs were also compared in terms of contours drawn with an interval of 20 m. From the contours, we observed that optical stereo gave better contours than that of InSAR for Koyna test site. However, for Mumbai test site, the contours from InSAR are better than that of optical stereo. To exploit the complementarities of the two techniques, DEMs were fused by replacing holes in the InSAR data with the DEM derived from optical stereo technique. We did not observe much change in the contours of InSAR DEM after fusion. It is concluded that better data sets are required for DEM generation using optical stereo. Using better phase unwrapping techniques, one may get better DEM using InSAR technique.

1. INTRODUCTION

Optical stereo and SAR Interferometry techniques are being widely used for retrieving elevation information from images acquired through spaceborne platforms. These techniques are different from each other and they were described in several publications [1][2] and [3], [4]. In optical stereo, the coordinate difference between conjugate points (i.e image parallax) in both the images are measured for height extraction, whereas InSAR technique computes the height from the phase difference of the point backscatter in two passes.

Each technique has its own merits and demerits. Problems with optical DEM generation arise from cloud cover, low ground texture and temporal radiometric differences. Due to this, decorrelation takes place between two images and leads to point mismatching. The main problem with SAR interferometry processing chain is phase unwrapping. Since the phase differences are only known modulo 2π, the correct multiple of 2π has to be added to each phase values of inteferogram. The phase unwrapping algorithms [5] are usually applied when there is no phase jump above π between two adjacent pixels in the interferogram. The condition is not satisfied in layover, foreshortening, shadow and temporal decorrelation areas. Temporal decorrelation [6] between two SAR scenes is mostly due to vegetation and in areas of intensive land use. SAR data also suffer from changes in atmospheric conditions between two acquisitions [7].

We generated DEMs using both optical stereo and InSAR data over Koyna and Mumbai regions. The DEMs are compared with each other and also with GPS and topomaps. In subsequent sections, test site, data sources, processing of both optical and InSAR data, results and discussion are given.

2. TEST SITES

2.1 Koyna Test Site

The study area for this work was selected around Koyna covering 24 km x 27 km as we have ERS-1 and 2 SAR tandem data sets for this area through ESA AO-3 (Announcement of Opportunity). It is located in the western part of Maharastra state in Satara district and its topography varies from 150 meters to 1100 meters. At some parts of the area, slope of the hills are very high leading to distortions

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in both SAR and optical data. Some part of the site covers thick forest. Annual rainfall over this area is about 2500 mm and normal temperature is about 22^0C. The area comes under highly seismic active zone. Many earthquakes have occurred in the region since 1962. The strongest one was in 1967 with a M6.3 claiming about 200 lives. Over the time, 150 earthquakes of magnitude 4.0 were recorded.

2.2 Mumbai Test Site

The test site covers some part of Mumbai city and centered around IIT, Bombay. The scene covers 24 km x 27 km area in which urban settlements, lakes, coastal areas, reserved forest, hills, etc. are present. Elevation in this area varies from sea-level to 330 meters over hilly terrain. Some features such as salt pans, vegetation and water may decorrelate the images between two acquisitions or leads to point mismatch between two corresponding pixels.

3. DATA SOURCE

3.1 Optical Data

IRS-1C PAN stereo data pair was acquired over Koyna area for 14^{th} and 18^{th} Feb., 2002 covering an area of 24 km x 27 km (4096 pixels x 4606 lines with spatial resolution of 5.86 meters). The scene acquired on 18^{th} is formed as right image and 14^{th} is as left image for stereo data processing. The image coordinates are shown in Fig. 1. View angle for 18th image is 13.518^0 and 14^{th} is -12.72^0. These angles give B/H ratio 0.47 through the following equation $B/H = \tan|\theta_1| + \tan|\theta_2|$. For obtaining good terrain elevation from stereo data, these angles should be large so that there would be an increase in the stereo exaggeration factor or equivalently the observed parallax. According to [11], B/H of 0.6 to 1.2 are typical values to meet the requirements for topographic mapping. Cheng et al. [12] generated DEM from raw IRS-1C LISS stereo-images with B/H ratio of 0.52 over a mountainous area in Arizona, USA.

IRS-1C PAN stereo data pair over Mumbai area is also acquired for 20^{th} and 29^{th} of March 2000. The scene acquired on 29^{th} is formed as left image and 20^{th} one is as right image for stereo pair. View angle for 20^{th} and 29^{th} images are -18.4032^0 and 1.8389^0 respectively. For these angles B/H gives 0.365 which is less than that of Koyna test pair and not optimum for DEM generation.

3.2 SAR Data

ERS-1 and 2 SAR tandem data were acquired for April 17 and 18^{th} 1996 around Koyna covering 100 km x 100 km area. Out of all data sets available for DEM generation using ERS SAR data, tandem data acquired in April and May 1996 were good. Not only the baselines (B_|_ = 118, B|| = 56, B = 130.6 meters) that are suitable for InSAR, but the changes between two images are negligible as the interval between two image acquisition is only one day. However, in vegetation covered areas, repeat pass interferometry, as is the case in ERS-1&2 SAR data, induce decorrelation between the images. Similarly ERS-1 and 2 SAR tandem data were acquired for 25^{th} and 26^{th} May of 1996 with baselines B_|_ = 126, B|| = 65, B = 141.2 meters. The area covers around 100 x 100 km.

4. IRS-1C PAN STEREO DATA PROCESSING

PCI OrthoEngine software was used for processing of IRS-1C PAN stereo data for DEM generation. To extract the DEM from a stereo pair, it is necessary to match points in X and Y direction on one image with the corresponding point on the other image. The distance and direction of the separation determines the amount of parallax and the corresponding elevation. Initially, one image of a pair is to be brought into epipolar projection so that Y-parallax is reduced and most of the displacement is in X-direction. Using cross correlation of two images the displacements can be calculated for every pixel. A few GCPs are needed to solve collinearity equations which converts the image coordinates into ground coordinates or vice-versa [8],[9]and [10].

The model incorporates various distortions relative to the platform (position, velocity and orientation), the sensor (orientation angle), the Earth (geoid-Ellipsoid, DEM) and the cartographic projection (ellipsoidal – cartographic plane). The collinearity equations are written for instrumental reference system and converted to cartographic projection system using elementary transformations (rotations and translations). The model takes into account the following transformations (1) Rotation from sensor reference to the platform reference; (2) Translation to Earth's Centre; (3) Rotation which takes into account the platform time variation; (4) Rotations to take into account the Earth geometry; (5) Transformation to the map.

IRS-1C PAN scene acquired on 14 Feb. 2002 is taken as left image and 18th Feb. 2002 image is taken as right image while processing the data using PCI OrthoEngine software. About 14 GCPs were selected for stereo model setup, geocoding and registering the Koyna PAN stereo pair. The GCPs are taken from Survey of India toposheets. Out of 14 points, G001, 2, 4, 8 and 9 points were taken for stereo model setup, geocoding and remaining points were taken as check points. In addition to these points, some GCPs were selected to match the images with greater accuracy. We find difficulty to get more GCPs as the area is hilly terrain with vegetation.

Similarly GCPs were selected for Mumbai site. The coordinates of GCPs were measured using Trimble GPS systems and processed using GAMIT software. Out of 37 total GCPs, 30 were used for stereo matching and 7 were used as check points.

5. INSAR DATA PROCESSING FOR DEM GENERATION

Main tasks in SAR Interferometry are as follows:

1) Selection of suitable SAR pair
2) Raw data processing for SLC data (if the supplied data are in raw signals.)
3) Co-registration of SLC data.
4) Interferogram Generation
5) Flattening of Interferogram
6) Phase unwrapping
7) Phase to height conversion
8) Geocoding of height, intensity, etc., images
9) Representing height image in shaded relief map or contour map.

A small window of ERS-1 SAR intensity image of Koyna was extracted out of 100 km x 100 km scene. ERS-1 SAR SLC image is registered with ERS-2 SLC data and interferometric fringes, coherence, phase and heights were generated using Gamma software. Similarly, SAR image for Mumbai was extracted and the corresponding interference fringes and coherence images are generated.

6. RESULTS AND DISCUSSION

6.1 DEM for Koyna Test Site using Optical Stereo

DEM generated through IRS-1C PAN stereo data is shown in Fig. 1 after geocoding. The gaps i.e. holes in the DEM are due to mismatch between two images. Interpolation at these holes can be done using surrounding height values. It can be observed from Fig. 1 that the optical stereo technique fails to give DEM at the steep elevations (lower left) particularly hill slopes facing away from the sensor or satellite. From SOI toposheet, we observed that slope of the hills are very high at these places leading to geometric distortion in the image. The distortion in the SAR image occurs at the hills whose faces look toward the radar direction. This will be discussed in the subsequent sections.

We observed that the RMS error for GCPs is 20 meters, whereas for check points it is 42 meter. Out of many points, only one point deviates from the topomap value. We took some more random points from toposheet and identified the differences. For these points, the RMS error for stereo and InSAR derived DEMs are 16 m and 30 m respectively. As the contours of Survey of India toposheets are at 20 m interval, the errors are reasonable. The reason for large error in SAR image is due to the problem of identification of GCPs in SAR intensity image.

6.2 InSAR DEM for Koyna Test Site

From the interferogram of InSAR data, it is observed that fringe density is high at steep elevations. One fringe represents a height of 80 meters according to the following formula with parameters B_n = 118 m, λ = 0.056 m, θ = 23.3017 and r = 847.2504 km.

$$One\ fringe\ (dz) = \frac{\lambda r Sin\theta}{2 B_n}$$

Coherence image are also obtained using InSAR data. Bright areas in the images represent high coherence and dark areas represent low coherence. Coherence is nothing but correlation between two images and varies from 0 to 1. High coherence is observed at the right side of the image, whereas low coherence (dark) is seen at steep areas with vegetation cover. Movement of the leaves causes decorrelation between two images.

From the geocoded DEM of InSAR as shown in Fig. 2, we observed that there are many gaps due to layover and shadow in the DEM. Height information over these areas can be obtained if ascending pass data are available. At present, only descending pass data are available with us.

6.3 DEM for Mumbai Test Site using Optical Stereo

Geocoded DEM generated using IRS-1C PAN stereo pair of Mumbai test area is also contained several gaps (holes). The gaps in the DEM are due to decorrelation between two image points. There are number of holes in forested area where decorrelation is high. Some boundary areas (bright areas) also show wrong DEM values. These are also due to mismatch between two pixels. These wrong DEM values are to be corrected manually. The reason for this mismatch is that there was long duration (9 days) between two acquisitions and also due to small B/H ratio. The RMS error in estimating heights is 10 m.

6.4 InSAR DEM for Mumbai Test Site

Interferogram for this site is also obtained using ERS-1&2 tandem data. From this interferogram, we observed that there were atmospheric effects that cause some patches (round shaped) at many places in the image. The coherence image of this area shows low coherence in forested area where coherence loss was observed due to movement of leaves. Some highly undulating areas also show low coherence due to layover and foreshortening. DEM is derived from interferogram after phase unwrapping. From this DEM, we observed that the number of holes are less than that of optical DEM. RMS error in the estimation of height values is 16 m for 25 GCPs.

7. Comparison of DEMs in terms of Contour Maps

Contour maps from both DEMs (stereo and InSAR) were generated for Koyna test site with a contour interval of 20 m. For example, a small part of the contour maps obtained from both the techniques are shown in Fig. 3 and 4. The following observations were made from these contour maps.

1) The contours are smooth in optical stereo DEM as PCI OrthoEngine interpolates DEM values. The contours are very close to that of SOI topomap.
2) The contour maps are very fine in InSAR DEM though they deviate from topomap at some points. No interpolation was done in the InSAR DEM.
3) Some spurious contours confined to a small region were observed in optical stereo DEM. These are shown with an arrow mark.
4) Elevated objects with slopes facing the sensor are observed with fine details in optical stereo, whereas the slopes facing away from the senor are observed with greater details in InSAR. The corresponding contours are also fine in the respective DEMs.

8. CONCLUSIONS

DEM derived from IRS-1C PAN is better than that of InSAR for Koyna test site, whereas for Mumbai test site, InSAR DEM is better than that of IRS-1C PAN stereo. Because of different viewing geometry of two sensor systems, quality of DEM at hilly terrain with slopes directly facing or facing away from the sensor system are different for both the data sets. Hilly terrain with slopes facing away from the sensor is good for InSAR technique, whereas it is disadvantage for optical stereo. Effect of vegetation is observed in both the techniques and it deteriorates the quality of DEM. Better image matching and phase unwrapping techniques may be attempted to get a better DEM through these techniques.

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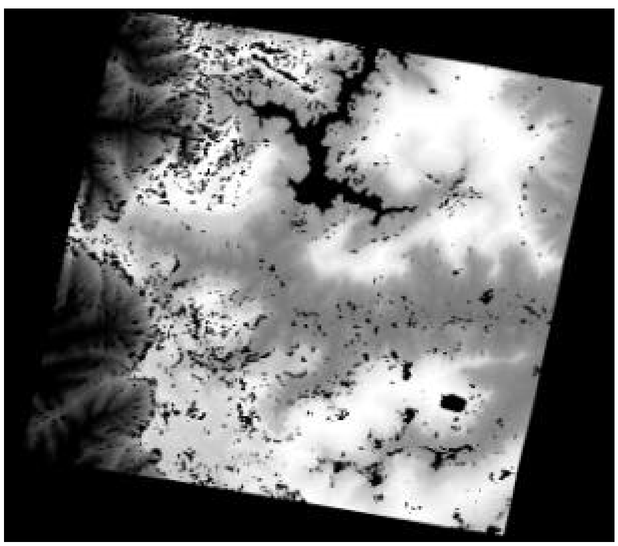

Fig. 1. Height map obtained using optical stereo data for test site 1.

Fig. 2. Height map obtained using InSAR data for test site 1.

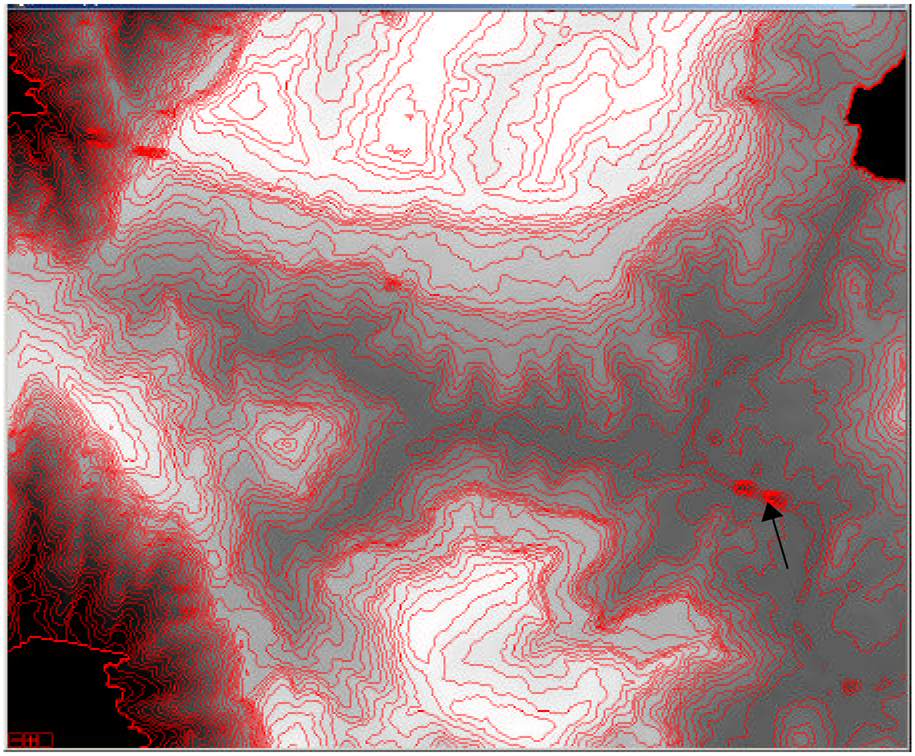

Fig. 3. Contour map of a small part of DEM derived from IRS-1C PAN stereo data.

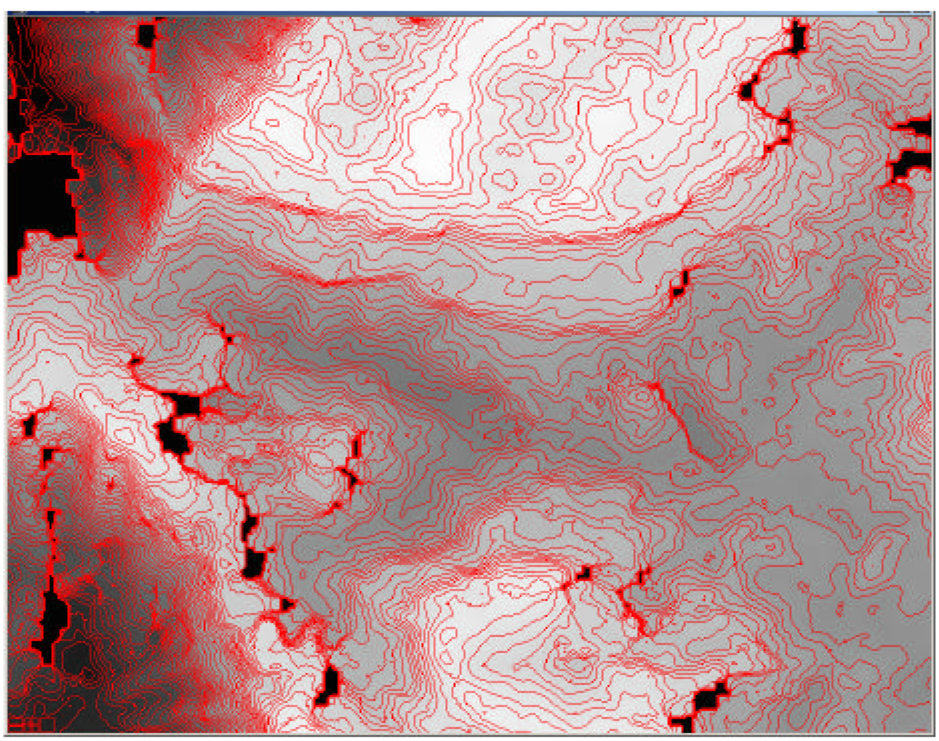

Fig. 4. Contour map generated using DEM derived from InSAR (ERS-1&2 tandem) data.