SAR INTERFEROMETRY BASED DISPLACEMENT MAPPING OF CULTURAL HERITAGE SITES

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KEY WORDS: Co-registration, Interferogram, Coherence, Displacement Map

ABSTRACT: Synthetic Aperture RADAR remote sensing has been widely used for mapping of archaeological features which include cultural as well as natural heritage sites. In the current scenario, SAR Interferometry has the potential to measure displacement and elevation of the objects appearing on earth's surface. Prime focus of present study is to evaluate the potential of C-Band SAR interferometry for subsidence mapping of cultural heritage sites. For this study, Rohtasgarh Fort was selected as study site and C-Band interferometric pairs were used which were acquired in March and April' 2017. Interferometric processing for interferogram generation, coherence and phase unwrapping was performed to generate a displacement map. High value of coherence was observed on the fort boundaries because this behaves as stable scatterer which wasn't changed during second acquisition and low coherence value was recorded for vegetation inside and outside the fort. Displacement map was generated from unwrapped interferogram with 0.3 threshold value of coherence. Most areas in and around the fort hadn't shown any displacement but an upliftment of 10mm was seen inside the fort premises. Upliftment in displacement map in fort premises may be possible either due to increase in moisture or dust storms while subsidence outside the fort premises can be due to loose debris washed away by rain.

1. INTRODUCTION

With the advent of satellite based remote sensing, its various applications in a number of domains were explored. Archaeology was one such domain where optical remote sensing data was used for mapping and change detection of archaeological sites and to suggest necessary protection measures (AH Jhang, 2017). But a major breakthrough was made when microwave remote sensing came into picture and ground penetrating RADARs were increasingly used to find out hidden layers of archaeological sites as non-invasive tools (Parcak, 2009). Since they had penetration capability and were independent of clouds or rain, their versatility in this field remained un-questioned.
Interferometric Synthetic Aperture RADAR (InSAR) is a technique that is used to map the ground deformations, where RADAR images collected at two different time periods from nearly same point are compared against each other. Any movement of the ground surface with respect to the satellite sensor either towards or away from it can be measured or portrayed as a picture. This represents as to how much the surface got deformed in the time between the acquisitions of the two images. For this purpose, a RADAR pulse is emitted and after scattering it is recorded back at the satellite sensor giving phase and amplitude deformations. Changes in distance between two images are shown as phase difference. Combining these two images acquired at different time periods, we get an interferometric RADAR image as the combining two waves reinforce each other. This technique greatly helps scientists and archaeologists to monitor deformations that occur over large areas like the Rohtasgarh fort and produce displacement maps with centimeter level accuracy. This technique is useful in areas where ground level monitoring is difficult due to inaccessibility or hostile weather and local conditions. (Helz, 2016)

2. STUDY AREA AND DATASETS

2.1 Study Area

The study area taken is the fort at Rohtas District located on a hill top at an elevation of about 2000ft above sea level. Rohtasgarh is situated on the upper course of the river Son, 24^{o} 57′ N, 84^{o} 2′ E. The reflectivity map with values of reflectivity ranging from 0-2.5, as shown in Fig.1 (a) shows high values for the fort boundaries. The 2000 odd limestone steps were probably meant for elephants, as shown in Fig.1. (b). The staircase was so strongly built that most of it has survived the test of times and is intact till date except for a few minor losses. The fort commanded a strategic position in medieval era as it stood guard over the important land and riverine trade routes passing from the fertile doab region of Ganges and its tributaries, reaching for up to the Bay of Bengal. For the visitor they are exhausting climb of an hour and a half. At the end of the climb, one reaches the boundary wall of the fort. A dilapidated gate with a cupola can be seen there, which the first of many gates is provided for well-guarded entrances to the fort. From here one has to walk another mile or so before the ruins of Rohtas can be seen, Fig.1. (b).

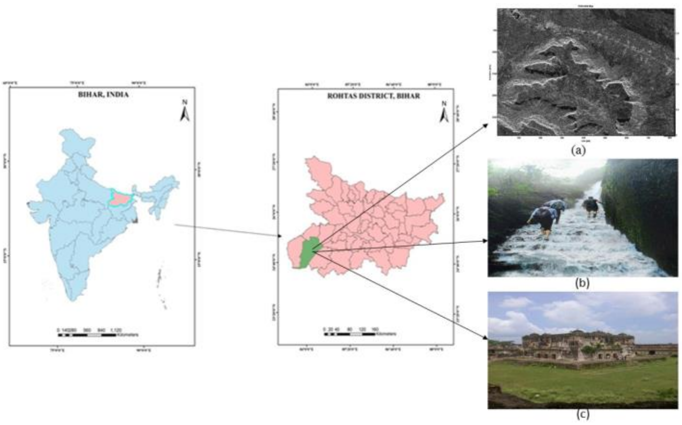

Fig.1. Study Area

(a-Reflectivity map of the fort site, b- staircase leading up to the fort, c- palace inside the fort)

2.2 Datasets

The datasets used were Single Look Complex (SLC) pair of same path and row number acquired in descending mode from Sentinel 1A Satellite, since they are freely available datasets operating in C-Band at 5.5m Spatial Resolution. One dataset used was that of March First 2017 while other was that of April thirtieth 2017.

3. METHODOLOGY

The methodology flow diagram is given as follows-

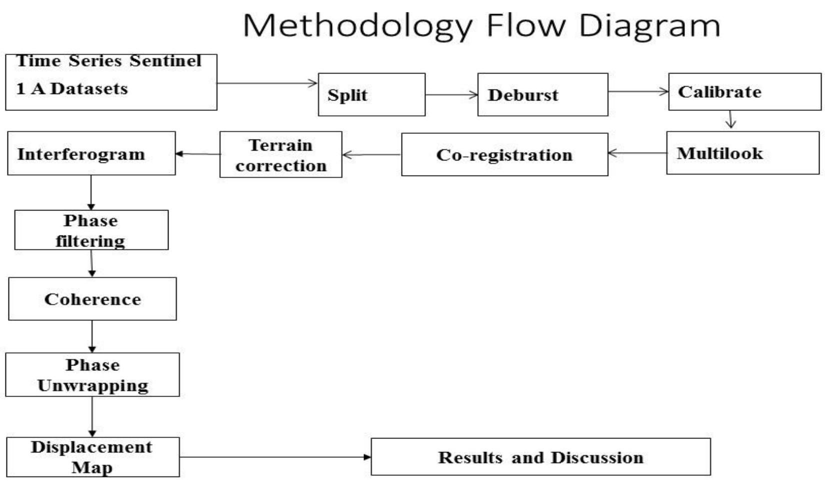

Fig.2. Methodology Used

The datasets were initially pre-processed, wherein the datasets were first Splitted then Deburst followed by Radiometric Calibration and Multilooking stages. Thereafter the study area was subsetted from both the datasets and both products were Co-registered into a single product. An Interferogram was generated for change detection and phase filtering was performed. A coherence of 0- 0.95 was observed. Thereafter the data was terrain corrected and speckle filtered to remove noise and an RGB image was generated showing backscatter signatures of different land cover features. The fort boundaries and ponds located inside the fort were clearly seen and were verified with Sentinel-2 optical data. The area in the fort premises showed peculiar backscatter that was different from the surrounding open land making it detectable quite well. Finally, phase unwrapping was performed to generate a DEM (Digital Elevation Model) and a displacement map was generated.

3.1 Pre-Processing

The datasets were pre-processed as follows-

3.1.1 Calibrate

The procedure of SAR Calibration radiometrically corrects the image so that pixel values truly represent the backscatter values of the reflecting surface. This also removes any radiometric distortion. Due to this the pixel values truly represent the backscatter values. To properly work with the SAR data, it should be first calibrated. This is especially true when preparing data for mosaicing where there are several data products with different incidence angles and relative levels of brightness. Since the corrections applied are all sensor specific, therefore it is decided by the software, as to what corrections have to be applied at time of calibration (ESA).

3.1.2 Multilooking

A single SAR resolution cell has two spatial resolutions, slant range and ground range resolution. As the slant range resolution has lot of ambiguity, to minimize this, slant range to ground range resolution conversion is done. The difference between the resolutions creates rectangular shape of the pixel. Multilooking is done to have an image of the nominal pixel size; on one hand where it increases the radiometric resolution on the other hand it degrades the spatial resolution. Here range resolution cells are averaged over azimuth resolution cells. Hence a resulting image of less noise and approximate squared pixel size when converted from slant to ground range. The resulting mean ground range resolution is 14.15m. However this is only an optional step and not necessary when terrain correcting an image. The resulting image will have 4 looks in range and one look in azimuth (ESA).

3.1.3 Co-registration and Terrain Correction

To co-register the different image subsets, we carry out the normal co-registration steps, as described in the introduction part, with the detected PT match patches. Since the speckle noise has been significantly reduced in the incoherent mean amplitude maps without spatial resolution loss, high amplitude cross-correlation can be expected. The objective of coarse co-registration is to obtain the approximate offset vectors for the center pixel in master image. Terrain Correction is used to geocode the image and producing a map projected product using DEM (Digital Elevation Model) by correcting all geometric distortions. This converts an image from slant or ground range geometry into a map co-ordinate system. DEM is used for inherent SAR geometry corrections for layover, foreshortening and shadow (Veci, 2016).

3.2 SAR Interferometry

SAR interferometry involves acquisition by two RADAR antennae on the same platform or with same satellite in repeated orbits at different times. SAR data was collected for the same area, with same SAR geometry. This study utilizes a pair of interferometric Sentinel-1 SAR data.

3.2.1 Interferogram formation

An interferogram is formed by cross multiplying the master image with the complex conjugate of itself. Interferometric Phase represents the phase difference that occurs due to backscatter received. Through this we try to remove the sources of error to be left. The phase formula is as follows (ESA)-

$$\varphi 1 = 4\pi R / \lambda \quad (1)$$

$$\varphi 2 = (R+dR)/\lambda \quad (2)$$

$$d\varphi = \varphi 2 - \varphi 1 = \text{Interferrometric phase difference} = 4\pi\,(dR)/\lambda \quad (3)$$

Where R is the satellite target distance and φ is the phase.
The regularly spaced phase band lines show flat land while irregular ones show change in topography.
To flatten the topographic phase, topographic phase removal and phase filtering is done. The interferogram is simulated based on a reference DEM which is subtracted from processed interferogram. Phase filtering increases the signal to noise ratio. Where there is loss of coherence, the interference pattern is lost. To be able to properly unwrap

the phase, the signal-to-noise ratio needs to be increased by filtering the phase. (Veci, 2016)

3.2.2 Coherence

The coherence between master and slave images show that the images have good similarity in between them and thereby good for DEM Generation. Loss of coherence can produce poor interferrometric results. Loss of coherence could be caused by temporal (time between acquisitions), geometric (orbit errors), volumetric (vegetation) or processing. The coherence band shows how similar each pixel is between the slave and master images in a scale from 0 to 1. Areas of high coherence will appear bright. Areas with poor coherence will be dark. Usually, vegetation is shown as having poor coherence and buildings have very high coherence. The coherence contribution equation is as follows (Sentinel-1 toolbox Tutorial, (Veci, 2016))-

$$\gamma = \gamma T \cdot \gamma G \cdot \gamma V \cdot \gamma P \qquad (4)$$

Where γT is temporal hence can’t be avoided, γG is geometric and can be partially avoided, γV is volumetric and can’t be avoided, γP is processing and should be avoided.

3.2.3 Phase Unwrapping

Due to the ambiguity of interferometric phase within 2π and to relate interferometric phase with topographic height. Phase unwrapping solves this ambiguity by integrating phase difference between neighboring pixels. The altitude of ambiguity H_a is defined as the altitude difference that generates an interferometric phase change of 2π after interferogram flattening （Sentinel-1 toolbox Tutorial, (ESA))-

$$H_a = (\lambda R \sin\theta) / Bn \qquad (5)$$

Where R is the Satellite-target distance, H_a is the altitude of ambiguity, θ is the phase angle and λ is the wavelength. Phase unwrapping solves this ambiguity by integrating phase difference between neighboring pixels. After deleting any integer number of altitudes of ambiguity (equivalent to an integer number of 2π phase cycles), the phase variation between two points on the flattened interferogram provides a measurement of actual altitude variation.

4. RESULTS AND DISCUSSION

4.1 Interferogram

Interferogram is used to monitor the surface deformation by analyzing the change in phase of the waves returning back to the RADAR sensor. The interferogram shown below, shows abrupt change in fringe colors showing change in topography at a few places. Though the phase remains unchanged in most places, at a few places there is abrupt phase change with value ranging from -3 to 3 radians for the respective color fringes, that showed abrupt phase change across the edges of the boundary of the fort, as shown in the following map, with fort boundaries at present times which are in three layers that make it a strong and significant fortification of old times- (a), (b) and (c), (Fig.3)-

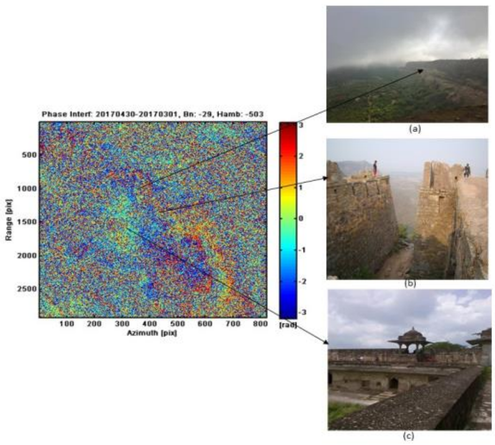

Fig.3. Phase Flattened Interferogram
(a- outer fort boundary, b- peripheral fortification, c- inner boundary)

4.2 Coherence

Coherence shows there is any similarity between master and slave images for DEM generation. Similarity between master and slave images, shows good coherence. Loss of Coherence. A coherence value of 0- 0.954 is seen. The Coherence map given below shows the same. Here as we can see good coherence is seen for the fort boundaries while poor coherence is seen for the vegetation inside and outside the fort. Shown below (Fig.4) is the coherence map.

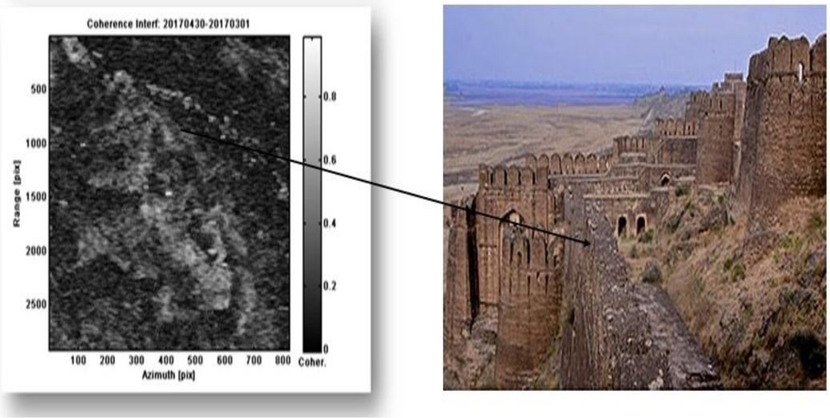

Fig.4. Coherence map (SARPROZ) with the Fort boundary photograph (*Courtesy, http://www.i.ytimg.com)*

4.3 Displacement Map

The displacement map shows no apparent shift in coherence in most places and least shift in and around the feature conforming to presence of some permanent feature. This is shown by the displacement map in Fig.5. However at few places significant displacement is seen. This is due to change in topography or dielectric constant of the material causing change in backscatter values. However no phase change at most places also confirms the presence of the archaeological feature on the hill top. Displacement map shows displacement values in the range of -10 to 10mm. This means that there has been upliftment at few places which can be due to rain water accumulation or dust storm at time of acquisition, inside the fort boundary. Presence of long standing grass also confirms this fact as seen during the field visit to the site, Fig.5 (a,b). Some places also show subsidence, mainly in and around the fort which is caused by rain water washing away the loose debris. Fig.5. shows this, the actual site photographs taken reveal that there is presence of vegetation inside the fort premises, which means water accumulation is a common phenomenon in rains, which is showing upliftment in the displacement map. Presence of loose debris around the fort confirms subsidence due to it getting washed away by rains.

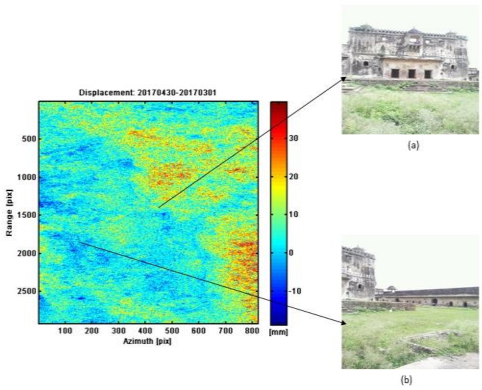

Fig.5. Displacement Map, with site photographs
(a, b- Presence of grass inside the fort)

5. CONCLUSION

SAR Interferometry is an upcoming tool with lots of potential in the field of archaeology, firstly due to its all-weather availability and secondly due to its unique ability to measure and map and displacement and deformation that has occurred in a monument of national importance like the Rohtasgarh fort. As A non-invasive tool, it does not put any potential harm or threat on the monument. On the other hand proves excellent to study any changes that have occurred at sites located in remote and inaccessible areas like this one. This can help archaeological departments and the government to take remedial measures to protect the rich cultural heritage of this country with a five thousand year old civilization and a rich multicultural past.

6. ACKNOWLEDGEMENTS

For this research, heartiest gratitude is expressed to the support extended by the Indian Space Research Organization (ISRO), the European Space Agency (ESA), Alaska Satellite Facility (ASF) and the SARPROZ software developer's team.

5. REFERENCES

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