Defence Science Journal, Vol. 63, No. 1, January 2013, pp. 69-73, DOI: 10.14429/dsj.63.3766

Coherent Change Detection with COSMO SkyMed Data-experimental Results

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ABSTRACT

Change detection is a technique in which we try to find changes between two acquisitions. These acquisitions can be from different platforms and sensors. Acquisition from satellite using synthetic aperture radar (SAR) is of immense interest to military applications. Satellite has the ability to peep into the enemy territory while SAR has the capability of day and night operations, being an active sensor. Coherent change detection (CCD) can be used to detect minute changes between two images. This paper presents the coherent change detection experimental studies using COSMO SkyMed space borne data. It has been demonstrated that subtle changes caused by the vehicle movement can be detected using phase characteristic of the SAR data.

Keywords: Coherent change detection, synthetic aperture radar, track detection

1. INTRODUCTION

Change detection finds usage in number of remote sensing applications viz. battlefield damage assessment, updating old maps, monitoring of area of interest (AOI), etc. AOI monitoring refers to continuos observation and assessment of a particular site. Electro-optic sensors cannot monitor those AOI which are constantly under cloud coverage or where the changes are very minute. Being an active sensor, the SAR has the ability to overcome these difficulties. Two type of change detection can be performed using SAR data. First is the incoherent or amplitude change detection (ACD), which compares the backscatter between the two scenes to find out changes. Here since the images used are multi-look detected images, therefore its capability to detect very fine changes is limited. Second is the coherent change detection (CCD) which exploits the coherence between the two scenes. Any de-correlation in the phase will manifest as change in coherence. Loss or low coherence signifies change. Since the phase is very sensitive to minor changes hence CCD has the ability to detect subtle changes like movement of troops or vehicle. CCD is basically the spin off of SAR-Interferometry where the two complex images are interfered to generate the interferogram. This paper focuses on the CCD technique and aims in detecting tracks caused by the movement of vehicle of the order of few metres. It showcases the potential of COSMO SkyMed satellite data which is an X-band SAR system, in detecting minor changes.

Williams[1], *et al.* have demonstrated that an X-band, repeat-pass, spotlight SAR CCD system may be used to detect changes associated with tyre tracks resulting from vehicle passage when those tracks are wider than the SAR resolution. Tsunoda[2], *et al.* has described the Lynx-UAV system and its ability for CCD using complex un-detected images. Corr[3], *et al.* has used the ERS-SAR data for detection of vehicle movement. Since the resolution and range bandwidth of ERS data was poor, hence the detected tracks were very faint and cannot be further used for automated processing. Scheuchl[4], *et al.* has used TerraSAR-X for detecting racing tracks in Bonneville salt flats. The detected tracks are considerably long and are in kilometers. In this paper we will present experimental results where we have detected very small vehicle tracks of the order of tens of meters using COSMO SkyMed satellite data.

2. BACKGROUND

COSMO-SkyMed satellite system is managed by Italian Space Agency. The system consists of a constellation of four low earth orbit mid-sized satellites, each equipped with a multimode high-resolution synthetic aperture radar (SAR) operating at X-band (9.6 GHz). Apart from other modes, it provides one meter resolution spotlight mode with approximately 7 x 7 km imaging area. Due to four identical satellites it has the advantage of short revisit time (one day) which is highly desirable for CCD applications. With a range bandwidth of 369 MHz it provided relaxed critical baseline.

Table 1. Satellite acquisition details

Scene latitude	19.33°
Scene longitude	72.8765°
Imaging mode	Spotlight mode-2
Beam mode	ES-03
Local time of pass	1832 Hrs
Satellite number	31 May 2012 (Pass 1) COSMO 2
	01 June 2012 (Pass 2) COSMO 3

Received 24 September 2012, revised 29 October 2012, online published 24 January 2013

The test area was selected near Mumbai in Thane District. The village name was *Maljipada* in Tehsil Damai. The selected scene included backwater, bridges, roads, fields, settlement etc. *Maljipada* is a small village surrounded by small agricultural fields of approximately 50 m x 50 m. Due to water salinity, only one rice crop is harvested in a year during monsoons. Most of the fields were hard, cracked, and unploughed.

3. FIELD WORK

To facilitate data marking and registration of the two data sets trihedral corner reflectors were placed at the site area. The corner reflector was to be placed near the village area consisting of building, electricity poles and microwave towers. Large size of corner reflector was chosen so that it can be easily identified against the village surroundings. Generally in order to recognize a corner reflector in a SAR image, the difference in the backscattering coefficients of the corner reflector and its surroundings should be larger than 20 dB. When the symmetry axis of the corner reflector overlap with the radar sight line the radar cross section (or backscattering coefficient) of the corner reflector reaches its maximum value which is given by[5]

$$\sigma_{max} = \frac{\pi l^4}{3\lambda^2} \tag{1}$$

where λ is the wavelength and l is the trihedral reflector side. In the case of COSMO SkyMed, λ=3.125 cm. For l=225.92 cm, we get σ_{max}=44 dB.

On 31 May 2012 reflectors were mounted at the test site. On 01 June 2012 tracks were made on the field by a tractor with various patterns (cross, rectangle, circle, linear, etc.). A small field which was already ploughed was re-ploughed to see the coherence change. GPS measurements were also taken of the activity area. Figure 1 shows the COSMO SkyMed satellite coverage of the test area. The formation of tracks on 01 June 2012 by vehicle movement is shown in Figs. 2 and 3.

Figure 1. COSMO SkyMed satellite coverage. Test area marked in red.

Figure 2. Hard field were ploughed by the tractor.

Figure 3. Tyre marks were made on already ploughed fields.

4. DATA PROCESSING

The pair of single look complex (SLC) pertaining to the earlier mentioned two dates was processed to form the coherence image. The baseline between the two pass was calculated as 242.84 m from the ephemeris data. With so less baseline the problem of data de-correlation was negligible. The images were co-registered to sub-pixel level. The registration was performed in two steps. Image of 31 May 2012 was taken as master image while that of 01 June 2012 as slave image.

4.1 Coarse Co-registration

In coarse co-registration the master and slave images were registered up to one or two pixel accuracy. 512 x 512 pixel windows were selected in master and slave images. Let master image be $I_1(x,y)$ and the slave image be $I_2(x,y)$. The cross-correlation is define as-

$$\mathrm{Corr}(I_1(x,y), I_2(x,y)) = E[I_1 I_2^*]/\mathrm{sqrt}(E[I_1 I_1^*]\ E[I_2 I_2^*]) \tag{2}$$

Cross correlation was computed and the slave image window was moved to find the position for maximum correlation. The slave image was then shifted to match the master image.

4.2 Fine Co-registration

The level of fine co-registration depends upon the phase error. Normally in SAR Interferometric data phase error of 30-40 degree is observed. Since the phase range for SAR images is always 360 degrees (2π), roughly 1/10 pixel has become widely accepted for fine co-registration.

We first select two windows (size 512 x 512 pixels) in the master and slave image. These windows were then over-sampled ten times using sinc interpolation kernel. Again the cross-correlation method was used to find the fine shift.

The coherence γ in an area (X, Y) between the two images was then computed using[6]

$$\gamma = \frac{\left|\iint_{x,y} A_s(x,y)A_m(x,y)\phi_s(x,y)\phi_m^*(x,y)\,dy\,dx\right|}{\sqrt{\left(\iint_{x,y}|A_s(x,y)|^2 dy\,dx\right)\left(\iint_{x,y}|A_m(x,y)|^2 dy\,dx\right)}} \tag{3}$$

where $A_{m,}$ $\phi_{m,}$ $A_{s,}$ and ϕ_s are the amplitude and phase of the co-registered master and slave image respectively.

5. RESULT AND DISCUSSION

The full scene co-registered images of the two dates are shown in Figs. 4 and 5 respectively.

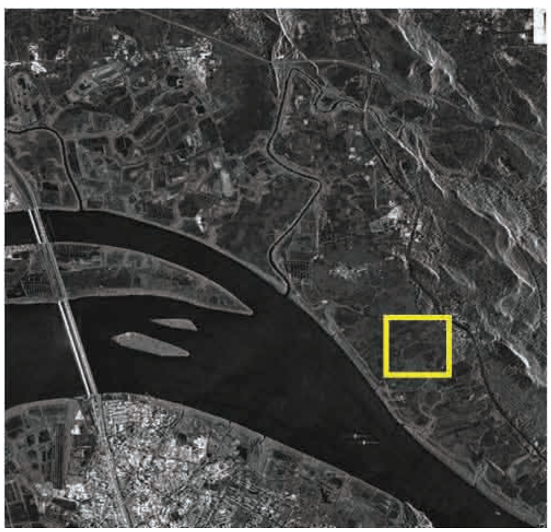

Figure 4. Full Scene registered SAR image of 31 May 2012.

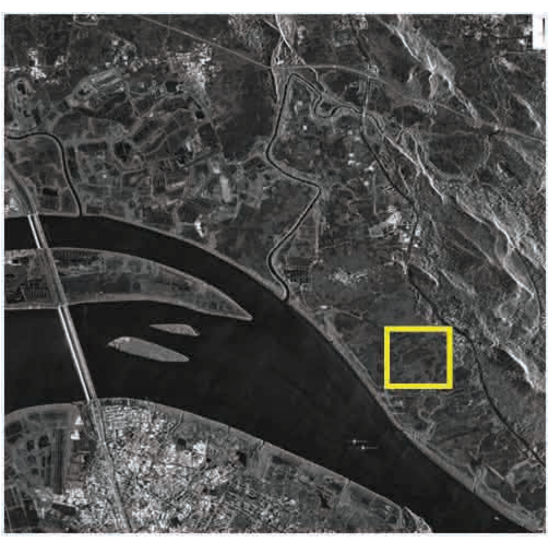

Figure 5. Full Scene registered SAR image of 01 June 2012.

Figures 6 and 7 shows the intensity image of the test area in full resolution. The corner reflectors are clearly visible in both the images. The rectangular blocks of different shades seen in the image are small fields of approximately 50 m x 50 m area. In these fields the tractor tracks were made in the afternoon of 01 June 2012. In the intensity image of 01 June 2012, which was acquired by the satellite in the late evening no changes are visible. The subtle details of the tyre track marks cannot be detected in the intensity image.

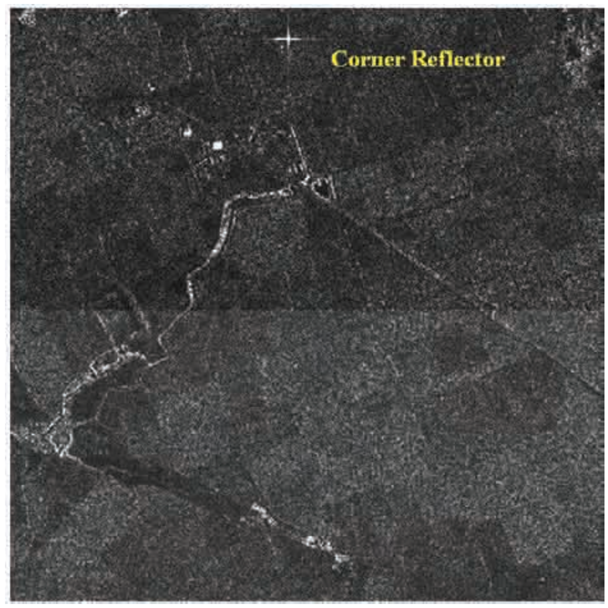

Figure 6. Test site intensity image of 31 May 2012.

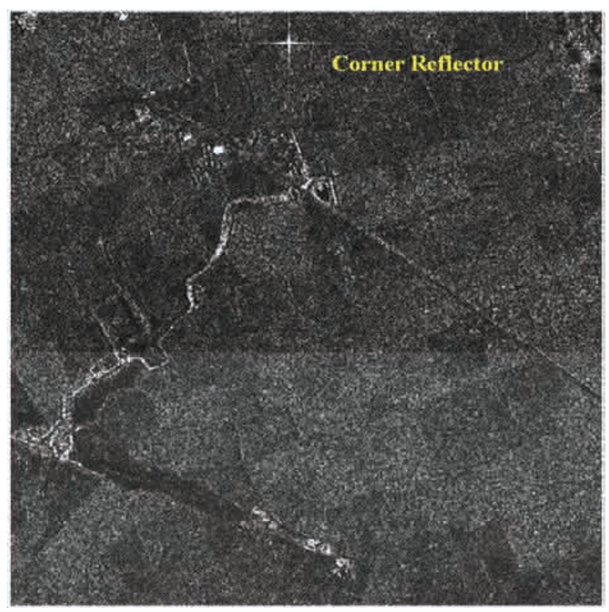

Figure 7. Test site intensity image of 01 June 2012.

The fields of the *Maljipada* village were of two categories. Some of them were not ploughed and were hard and cracked. These were ploughed by the tractor and the track mark thus produced were around six inches deep with loosened earth all around. This is shown in Fig. 6. The other category was of those fields which were already ploughed. In these fields the earth was a bit soft and soil loosened. No ploughing was done in these fields and the tractor was simply moved over it. The tyre tracks thus produced were very shallow and approximately one inch deep. This is depicted in Fig. 7. Some of the previously ploughed fields were re-ploughed by the tractor. All of these changes were not captured in the intensity image of 01 June 2012.

GPS readings were taken of the produced changes during the exercise. These were overlaid on the intensity image and are shown in Fig. 8. The changes were made in specific shapes viz. rectangular, circular, and linear. The coherence image of two dates is illustrated in Fig. 9. The coherence is dependent on the phase and is very sensitive to any change. Low coherence indicates changes while high coherence indicates no-change. Four areas A, B, C and D are marked in Fig. 8. They correspond to different changes between the two scenes.

A – Tyre marks on the soft ploughed field.
B – Ploughed tracks in hard field.

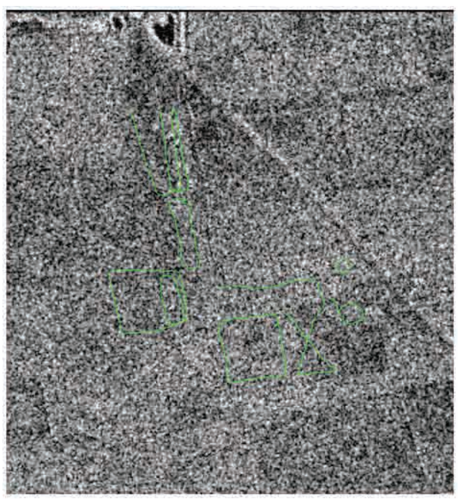

Figure 8. Test area amplitude image with overlayed GPS data.

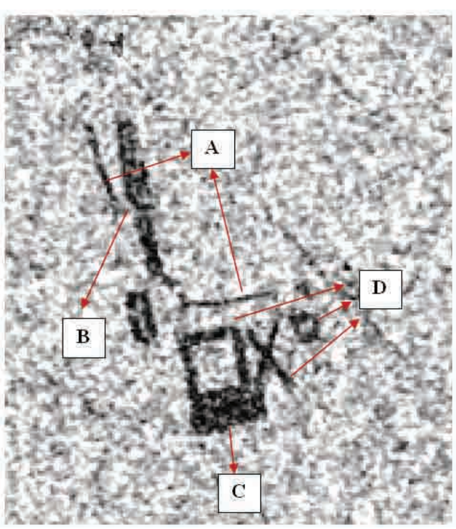

Figure 9. Coherence image (31 May 2012 & 1 June 2012).

C – Ploughed field which was again re-ploughed.
D – Different ploughed shapes (rectangular, circular and criss-crossed)

In the coherence image all these four areas are manifested as low-coherence. It shows the ability of coherence to capture minor changes which are otherwise not detectable in intensity image. The ability to detect low coherence target depends upon the target and background coherence and the separation between them. It also depends upon the number of looks required. Statistical formulation for the detection of target activity using Coherent Change Detection from SAR images is given by Mishra[7], *et al.* The amount of smoothing (number of looks) required to detect statistically significant targets is an issue in coherent change detection. We need more extensive smoothing as difference in coherence between the target and clutter reduces. This imposes a limit on the size of targets that could be statistically detected. In the present case background coherence $\gamma_b = 0.78$ and target (activity tracks) coherence $\gamma_b = 0.16$. With this coherence and meter resolution the number of looks required to detect a target with statistical significance of $\Delta = 3$ comes out to be 24. This means that the target size which can be detected is approximately 4.9 m. The tractor tracks made during the exercise were around four meters wide and were detected. This closely matches with the theoretical evidence.

Figure 10 shows the CARTOSAT-2B image of the same area taken on 05 June 2012 with 0.8 m resolution. As can be clearly seen none of the changes are visible in this image also. With this exercise we have demonstrated that subtle changes which are not detectable in electro-optical images can be detected by CCD technique. Scheuchl[4] has detected very long racing tracks, but here we have detected tracks of the length of forty to fifty meters.

Low coherence is also caused by vegetation, but the changes produced by them are random. Vehicle tracks are made in patterns, mostly curve-linear. In future work this detection

Figure 10. Cartosat 2B (0.8 m) image of 05 June 2012.

can be automated by designing algorithms which can detect curve-linear patterns automatically.

6. CONCLUSION

In this paper we have demonstrated that very minute changes caused by the movement of vehicles are manifested as loss of coherence in the coherence image. Experimental test bed was prepared at *Maljipada* village near Mumbai. Corner reflectors were mounted at the test site for referencing. Vehicle tracks were made at the test site under controlled experimentation and ground truth was collected using hand held GPS system. The tractor tracks made were of the order of tens of meter in length. COSMO SkyMed satellite images of the area were acquired before and after the changes. The baseline between the two passes was selected as to meet the condition for Interferometric processing. The data thus acquired was processed to generate the coherence change map. The subtle changes caused by the movement of the vehicle were successfully captured as loss of coherence in the coherence change map. The size of the change detected closely matched with the statistical formulation. It was also shown that these minute changes were not captured by high resolution panchromatic CARTOSAT-2B images. With the experiment presented in this paper we have proved that coherent change detection (CCD) is a powerful technique to capture those fine changes caused by any target activity which are not observable in optical images.

ACKNOWLEDGMENTS

The authors are grateful to Shri RC Agarwal, Director Defence Electronics Applications Laboratory (DEAL), Dehradun for granting permission to publish this work. The authors also express their gratitude to Mr VS Rathi, Group Head, IAC, DEAL for his encouragement.

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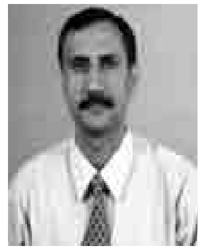

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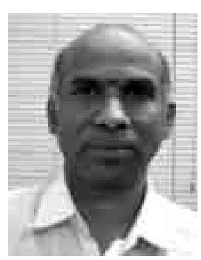

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