HIGH RESOLUTION SAR CHANGE DETECTION IN HONG KONG

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ABSTRACT

Both the resolution SAR image and acquisition period are significantly improved with the dramatically development in astronautics and microelectronic techniques, providing new opportunities for SAR specialists to analyze data whose information has never been as abundant as nowadays. In this work, we introduce two algorithms to handle high resolution SAR images: for spatial SAR comparison, we employ a normalized difference algorithm and a Wiener filter; for time domain amplitude analysis, we conduct analysis of variance, or ANOVA. The validation of both algorithms is verified by our campus experiment and successfully applied in the administration work of Hong Kong government.

Index Terms— ANOVA, Wiener filter, SAR

1. INTRODUCTION

With the rapid development of China and growing demand in monitoring large areas in a dynamic context, spaceborne change detection plays increasingly important role. Among the candidates, SAR change detection attracted exceptional research focus, due to its distinguished advantages of all-weather mapping capability.

One of the main challenging problems of SAR analysis is the issue of speckle, a complex multiplicative noise that derives from the coherent nature of the radar signal. Different methodologies have been proposed to deal with speckles, among them we recall ratio operators [1], adaptive filtering, automatic threshold selection [2], wavelet-based multiscale decomposition [3], Markovian integration [4], cumulant-based series expansions [5], Bivariate gamma distribution[6], Wishart distribution [7].

Notwithstanding the great efforts made in searching the best approach to detect changes from speckles in spaceborne SAR images, SAR techniques are still far from being adopted as operative tools for detecting ground changes. From one side, this can be adduced to the low resolution of existent SAR sensors, from the other side, to neglecting the possibility of analyzing long archives of data to get rid of speckle preserving the theoretical radar resolution.

Fortunately, with the launch of new generation high Resolution SAR satellites, the level of details visible in the SAR images dramatically increased. TerraSAR-X (TSX) and COSMO SkyMed (CSK) provide 1m resolution, and Radarsat-II 3m. Moreover, the revisit period has been decreased as 11 days for TSX, and even lower for the CSK constellation. The combination of these improvements provides us the opportunity to conduct long series data analysis for high resolution images.

In this paper, we introduce two methodologies for high resolution SAR change detection. For change detection from a single pair of images, our scheme incorporated a normalized difference algorithm and a Wiener filter. For change detection from long series of high resolution images, we generalize the concept of "temporary targets" published in [8, 9]. We consider multi-temporal amplitudes of a given target in SAR images and we apply an analysis of variance (ANOVA) identify the target changes along the time-domain series. The validation of these algorithms is verified by several empirical applications, two of which are demonstrated in this paper.

2. DATA SET AND METHODOLOGY

2.1. Data set

The data used in our work were acquired by the TerraSAR spaceborne SAR sensors, collected between 25 October 2008 and 26 December 2010 over the interested area of city Hong Kong. For multi-temporal amplitudes change detection, altogether 47 images were exploited; while for spatial change detection which utilizing Wiener filtering, images were analyzed by pair comparison.

2.2. Single pair images

For comparison of pixels between a single pair of images, a normalized difference algorithm is adopted in order not to overestimate the considerable small change in high grey areas:

$$\delta = \frac{a_1 - a_2}{a_1 + a_2}$$

And a Weiner filter is applied in order to filter out noise that retained in the output of normalized difference calculator:

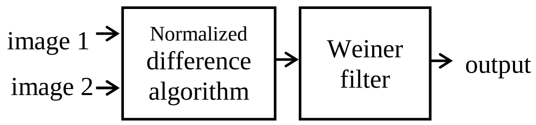


Figure 1: Comparison scheme for single pair image

2.3. Long series detection

In this section, the multi-temporal amplitudes of a given target in SAR images are considered and then an analysis of variance (ANOVA) [10] is applied to identify the target changes along the time-domain.

Provided that a sequence of SAR images is available, an architectural or land change that causes a different reflection of the radar signal is supposed to be detected by analyzing amplitude time series $R=\{R_t \mid t = t_{start}, \ldots, t_{end}\}$, where R stays for reflectivity. However, the information of radar reflectivity is deteriorated by speckle, a complex multiplicative noise that derives from the coherent nature of the radar signal. When speckle is present, amplitude variation can be observed even though the objects keep unchanged. In order to detect human-induced changes from speckle-induced ones, we conduct variance analysis, or ANOVA, to select pixels which exhibit statistically significant stepwise changes within the observed period.

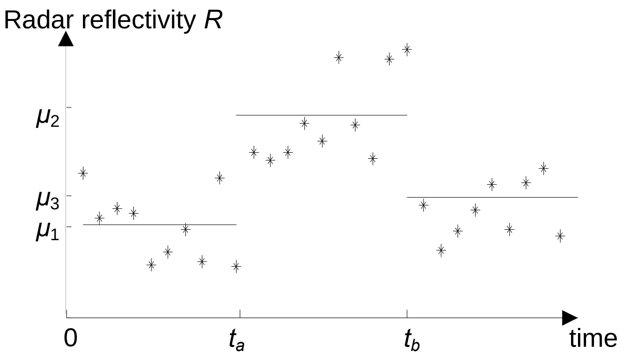


Figure 2: ANOVA for change detection in SAR series

We take 3-step model of change detection to illustration the algorithm. In ANOVA, we firstly raise the null hypothesis that "H_0: the interested area does NOT change at either t_a or t_b", or "H_0: $\mu_1=\mu_2=\mu_3$". In the hypothesis test, we analyze two estimates of variance to compare the three sample means ($\hat{\mu}_1$, $\hat{\mu}_2$, $\hat{\mu}_3$) to infer whether there is statistically significant differences among them. For convenience, the analysis of variance directly works with the term of the partition of sum of squares (SS), that is, sum of squared differences between pixels within each group (SS_{wg}) and their sample means (SS_{bg}):

$$SS_{wg} = \sum_i \sum_j \left(R_{ij} - \hat{\mu}_j\right)^2,$$
$$SS_{bg} = n \sum_j \left(\hat{\mu}_j - \hat{\mu}\right)^2,$$

where $\hat{\mu}$ is the sample mean of the whole observed set.

The differences of the two SS are evaluated as ratios F, where the variance associated with differences among sample means is in the numerator, and the variance associated with error is in the denominator:

$$F = \frac{SS_{bg}}{SS_{wg}/(n-2)}$$

where n is total sample number.

The ratio between these two variances (adjusted by their corresponding degree of freedom) forms an F distribution [10]. If the two estimates of variance do not differ appreciably by judging from critical F-test values, we conclude that H_0 is not rejected. In the second part of the procedure, we change the value of t_a, t_b, and conduct ANOVA again. The process is iterated until both t_a and t_b cover the whole sampled time range. If none of the null hypothesis is rejected, we draw the conclusion that no change happened during the observed period. If any of the null hypothesizes is rejected, we selected t_{a0} and t_{b0}, which are associated with the most significant result, and we conclude that the monitored spot changed at time: $t_{change1} = t_{a0}$ and $t_{change2} = t_{b0}$.

Theoretically, the algorithm is capable of classifying random number of groups, each of which has a random number of members. In practical consideration, it can be adopted to detect different kinds of change model including:

Model A. 2-step model of change, modeling the construction of a small building or minor work, with group number N= 2, group member n_1 and n_2 random number, and stability within each group.

Model B. 3-step model of change, modeling building constructions covering a period of several or more months, with group number N=3, group member random number, and stability within the first and last group.

Model C. 3-step model of change, modeling short-tern change in a long-term observation period, with group number N=3, group member n_1 and n_3 random number while n_2=1, stability within the first and last group, and $\mu_1=\mu_3$.

3. EXPERIMENT RESULTS

3.1 ANOVA verification – a campus study

For the purpose of algorithm verification, we selected the campus of the Chinese University of Hong Kong as our test site. The campus occupies 134 hectares in a mountain area in Shatin, the New Territories of Hong Kong. 47 TerraSAR high resolutions SAR images spanning a period of more than two years offered us an excellent opportunity to verify the algorithm performances.

Figure 3: SAR image of CUHK campus

In the case of variance analysis, we choose 2-step model of change as the target to test the validation of ANOVA. There are 70 points detected by the algorithm as change points. Among them, 18 points kept stable within one or both of the two partitioned periods. The time-domain amplitudes of these points and their location are shown in Figure 4.

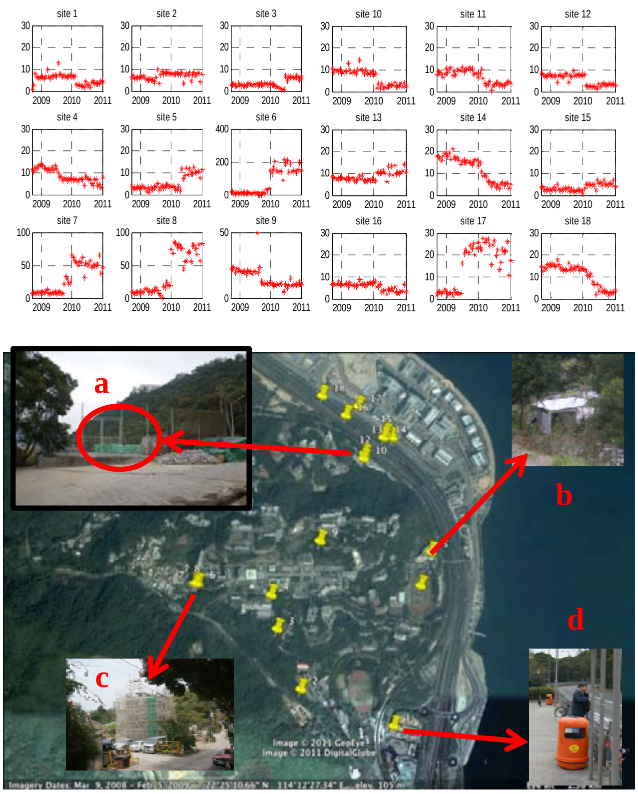


Figure 4: Examples of change targets detected in campus

Most of the detected sites exhibit a step model of change, corresponding to Model A described in last section: group number N=2 and points within each group keep stable. This may happened to be a cargo stacking ("a" in Fig.4), a small building ("b" in Fig.4), or objects like a rubbish bin ("d" in Fig.4). However, site 6-8 and 17 are different such that the points within the first period are stable but diffuse within the second period. This situation corresponds to the first and second parts of Model B: a large building is under construction and yet finished, as observed in ("c" in Fig.4).

All these points have a p-value of less than 0.0001, indicating that the probability of "no change happened between the two observation periods" is less than 0.01%.

3.2 Empirical Applications

3.2.1. Case 1 – spatial algorithm

In 2008, the Hong Kong government received a complaint of land and pond filling in private land. They inspected the site twice, and found that the entrance of a site was locked and there was no sign of any construction activity being carried out. Since it might be an enforcement case for filling of land, they decided to seek consultation from our institute. We analyzed this case by comparing high resolution images of this area (4699.4m^2).

We applied our algorithm in SARPROZ[11], and it automatically detected obvious changes within the area. In addition, it is observed that the delineation of boundary of specified area is important. Then we drew the following conclusions:

1) There is or was a dumping of material inside the pond.

2) The land filling process can be a rapid one. A pond or a piece of land can be filled at night and the land cover can totally change in the next morning.

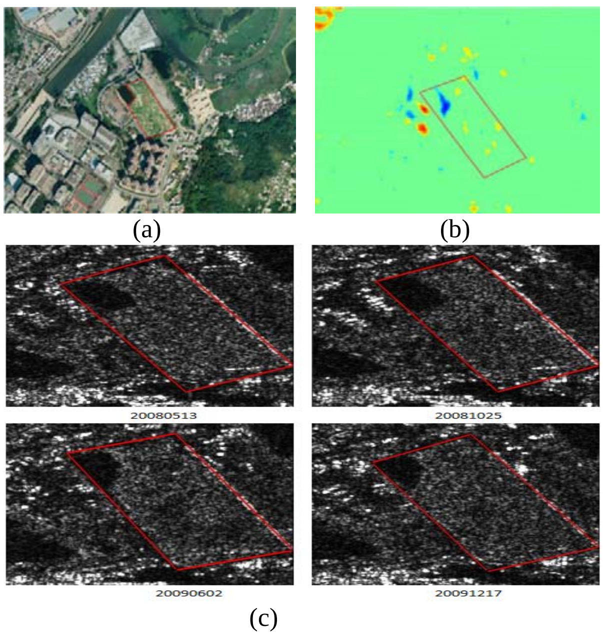


Fig. 5: (a) Birdview of testing spot 1 (b) result of single-pair comparison (c) boundary change

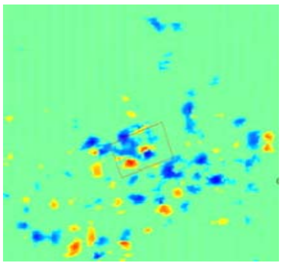
3.2.2. Case 2 – joint application

In the second case, the government authorized us to investigate a complaint referred by the 1823 Integrated Call Centre against unauthorized container depot use that was changed from vegetated land and pond to open storage of containers.

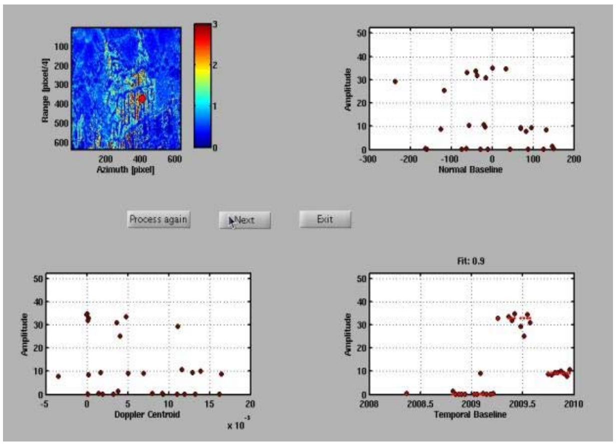
In this case, we are provided with a sufficient long series of images, so we analyzed this case by using both single pair images comparison and automatic long series detection. We applied the function of time-domain analysis in SARPROZ[12], and observed that the amplitude series exhibited a 3-step pattern which matches the Model B very well, as illustrated in Figure 6(c). The results present both visually and statistically strong evidence for unauthorized development on the land.

Based on our analysis results, as illustrated in Fig.6, we submitted our reports, addressing that the analyzed area had been (and had to be) empty, but later on was illegally used as an area for container storage.

(a)



(b)



(c)

Fig. 6: (a) Birdview of testing spot 2 (b) result of single pair comparison (c) result of long series detection[11,12]

Following our consultation reports, the Planning Department of Hong Kong government issued an Enforcement Notice to the two land owners, respectively. After that, both the land owners applied for permission under Section 16 of the Town Planning Ordinance for temporary alternative use for the lands.

4. CONCLUSION

In this work we exploited high resolution EnviSat SAR data to study the change detection application in Hong Kong. The proposed algorithm is validated by campus study and successfully applied in authority tasks, providing an application example of SAR images analysis in the field of systematic territorial surveillance.

5. AKNOWLEDGMENT

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