

Study on Corner Reflectors Identification in Highway Deformation Monitoring

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Abstract

CRInSAR is a newly developed technique to monitor ground deformation. In CRInSAR algorithm, the identification of Corner Reflectors in SAR images is necessary. Due to the uncertainty of traditional identification method, a new method based on the intensity and correlation coefficient of each CR candidates in SAR images is presented. The method has been successfully used to determine the locations of 11 CRs installed along a highway in six SAR images over the study area. The results show that the identification accuracy of the new method is about 1 pixel. It is effective and reliable especially in the area with lots of lightspots around the CR points. The method proposed can play important role in the highway deformation monitoring within CRInSAR algorithm.

Keywords: CRInSAR, Corner Reflector, SAR Coordinates, Highway, Deformation Monitoring

1. Introduction

CRInSAR (Corner Reflector Interferometric Synthetic Aperture Radar) is a newly developed technique of DInSAR (Differential InSAR). It can help us to obtain the deformation information based on the analysis of the phase changes of groups of CR (Corner Reflector) points installed in the study area preliminarily [1]. For that the backscatter characteristics of these CR points perform highly better than that of surroundings, each of them appears to be single light spot in SAR images (See Figure 1). CRInSAR has been successfully applied in ground deformation monitoring [2-3]. It can be obviously seen that due to the special structure and installation, the CR points can be identified easily from the image. In addition, with CRInSAR algorithm, the geocoding error in the processing of DInSAR caused by the external DEM can be avoided. As discussed above, it can be inferred that using CR points has great advantages in the application of deformation monitoring [4].

In the deformation monitoring algorithm using CRInSAR, the identification of CR points is a necessary step which can help us to determine the exact location (precise row and column information) of each CR point in each SAR image [5]. The traditional method used the longitude and latitude information of each CR point to inverse the initial row and column coordinate based on the Range and Doppler (RD) model and finally inversed the location of CR point under visual check and comparison[6]. This method has the following limitations: (1) there exist deviation between the inversed location and the real location of CR point; (2) due to the environment of the study area, there may appear to be more than one light spot

which may confuse the visual check and as a result lead the final location of the CR point hard to determine; (3) great uncertainty exists during the process of personal visual check and comparison. Due to these limitations, we will attempt to propose a more effective algorithm called Double Thresholding Algorithm (DTA) to determine the locations of CR points. This method will be applied to identify three groups of CR points installed along the highway in China from six PALSAR images.

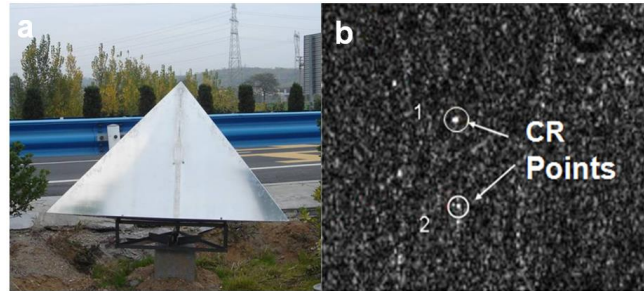


Figure 1. Photo of Artificial CR (a) and its Corresponding Performance in SAR Image (b)

2. Double Thresholding Algorithm (DTA) to Identify the CR Points

2.1. Principles

The inversion processing of the CR points' coordinates based on RD model has large system errors and may be influenced easily by the environment which may lead the phenomenon that more than one light spots appear around the CR point. As shown in Figure 2a, it can be seen that too many light spots distributed in the area which make it difficult to identify the true CR points. Due to this, the Double Thresholding Algorithm (DTA) will be proposed in this paper. Because of the high reflectivity, the CR points perform to have high intensity and corresponding high coherence. Considering both these two factors, we firstly use the intensity index to choose group of points as candidates initially, and then use the correlation coefficient index as criterion to determine the final location from the candidates.

Setting the intensity value of the k -th CR candidate to be expressed as dB_k which can be extracted from the intensity image, the corresponding correlation coefficient γ_k can be calculated by the mean of time series coherence, which can be written as[7]:

$$\gamma_k = \frac{\sum_{p=1}^N \gamma_p}{N} \quad (1)$$

where N defines the index of the time series interferometric pair; γ_p defines the coherence value of this CR candidate in the P -th interferometric pair [8, 9].

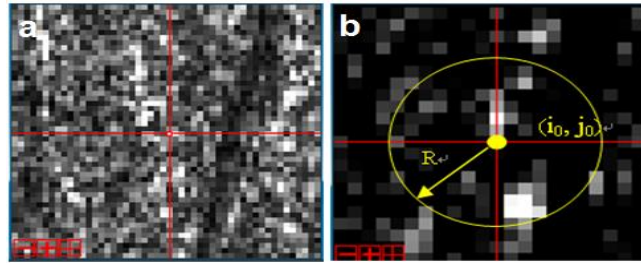


Figure 2. Possible Distribution of Light Spots (a) and Position of the CR Candidates (b)

2.2 Operating Process of the Algorithm

According to the principles discussed above, supposing the number of CR points needed to be identified in one image is $M+1$, the flow step of DTA is summarized below (the corresponding algorithm flow is shown in Figure 3):

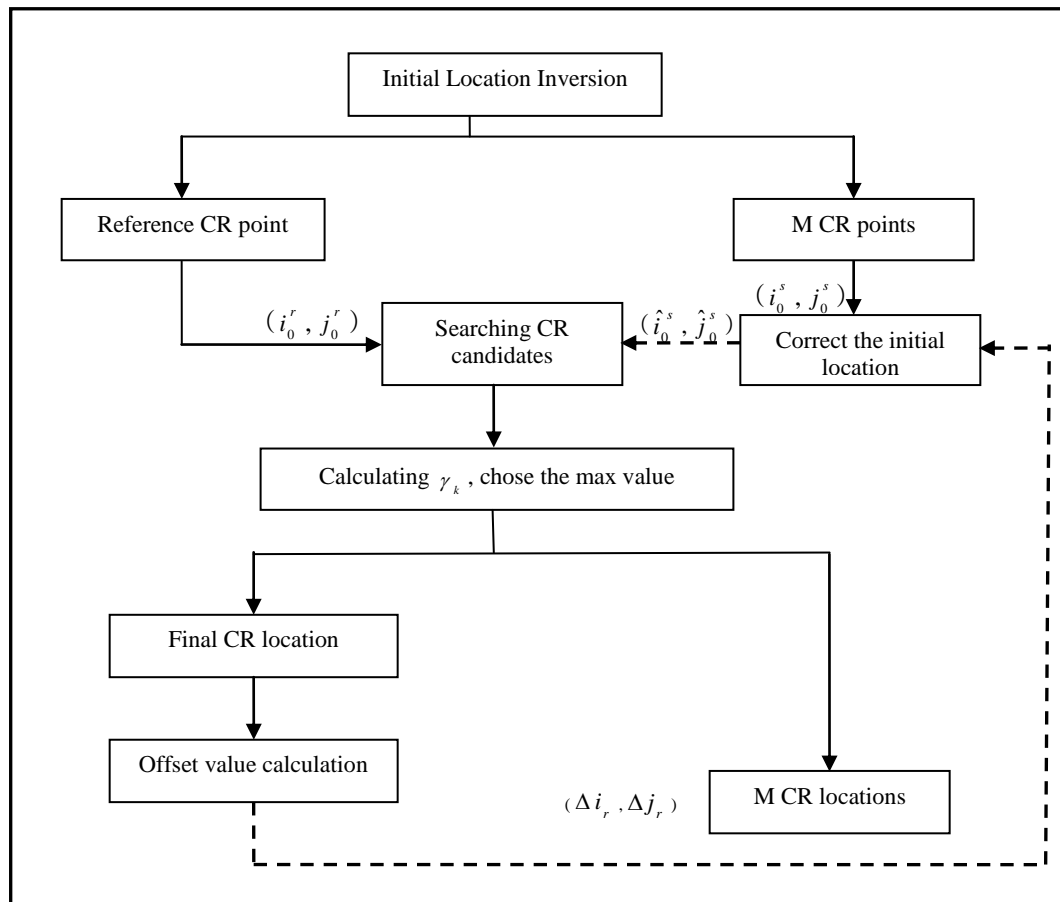


Figure 3. Algorithm Flow of the DTA

(1) Calculating the initial row and column information using RD model according to the altitude and latitude value obtained from the GPS receiver. The detail operating process of RD model inversion is introduced in [6]. One of the $M+1$ CR points is chosen as reference

point, the initial row and column value worked out is written as (i_0^r, j_0^r) , while that of the rest M CR points is written as (i_0^s, j_0^s) , where $s = 1, \dots, M$;

(2) Searching each of the light spots according to the intensity value in the area with the location (i_0^r, j_0^r) as center, R as radius (shown in Figure 2 b). The points with intensity value above the threshold index are chosen as candidates, being written as (i_r^1, j_r^1) , (i_r^2, j_r^2) , ..., (i_r^k, j_r^k) . As discussed above, due to the limitation of the natural environment, there will be the phenomenon that the contrast between the reflections of CR points and natural points is not obviously enough. We can use the ENVI software to enhance the contrast in order to make the identification of CR points more easily ;

(3) Calculating the value of γ_k on each CR candidates according to Eq. (1). The row and column value of the k -th CR candidate with $\max \gamma_k$ can be written as (i_r^k, j_r^k) , which can be taken as the final row and column value of this reference CR point (i_r, j_r) :

$$\begin{cases} i_r = i_r^k \\ j_r = j_r^k \end{cases} \quad (2)$$

(4) Correcting the initial location information of the rest M CR points. For the error of the initial row and column value obtained from RD model has systematic characteristic, the total offset value of all the calculated locations reference to the true ones are identical. According to this, after calculating the reference CR point's row and column information (i_r, j_r) , the offset value reference to the initial row and column value (i_0^r, j_0^r) can be written as $(\Delta i_r, \Delta j_r)$:

$$\begin{cases} \Delta i_r = i_r - i_0^r \\ \Delta j_r = j_r - j_0^r \end{cases} \quad (3)$$

The initial row and column value after correcting can be written as $(\hat{i}_0^s, \hat{j}_0^s)$, which can be calculated as follows:

$$\begin{cases} \hat{i}_0^s = i_0^s + \Delta i_r \\ \hat{j}_0^s = j_0^s + \Delta j_r \end{cases} \quad (4)$$

where $s = 1, \dots, M$, then the $(\hat{i}_0^s, \hat{j}_0^s)$ can be taken as center point, with step (2)- (3) being repeated the final location information of all the CR points can be calculated out.

3. Experiment

3.1. The Installation and Design of CR

In order to validate the proposed DTA above, three groups of CR points are installed along a highway in Henan province of China. Figure 4 shows the distribution of the CR points in

the master intensity image. The goal to install the CR points along the highway is to help monitoring the ground deformation of the highway. CR01, CR05 and CR12 are chosen as reference points in each group respectively.

In order to determine the locations of CR in SAR Images immediately and accurately, the shape and installation should follow certain discipline. The trihedral solid aluminium sheets are used in the design, which indicates that the scattering surface is isosceles right triangle (see Figure 5), the corresponding max RCS (Radar Cross Section Area) can be expressed as [10]:

$$RCS_{\max} = \frac{4\pi l^4}{3\lambda^2} \quad (5)$$

where l defines the length of corner reflector being 1.2m in the experiment. During the installation of the CR points, the following conditions are considered [11-12]:

(1) Azimuth: the orientation of CR should be coincide with that of radar LOS (light of sight), so that the RCS can reach the max value. The orientation is correlated with the orbit angle of radar, the longitude of CR's location and the azimuth of CR's hemline. The corresponding relationship function can be written as:

$$\beta = \arcsin \frac{\pm \cos \alpha}{\cos \zeta} \quad (6)$$

where β defines the azimuth of CR's hemline; α defines the slope angle of Radar orbit; ζ defines the longitude of CR's location;

(2) Longitudinal attitude: The horizontal side should keep level before the longitudinal attitude being determined. The longitudinal attitude should be adjusted according to Figure 5.

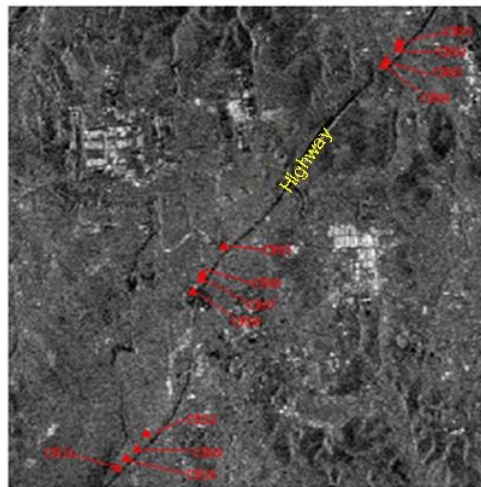


Figure 4. The Locations of CR Points along the Highway in the Master Image

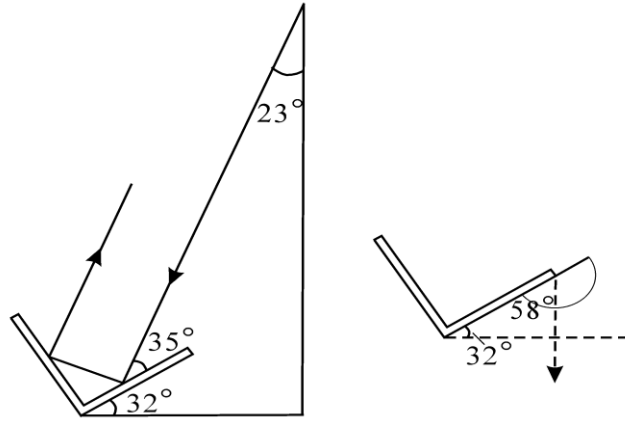


Figure 5. Isosceles Right Triangle Trihedral CR and Adjustment of CR's Longitudinal Attitude

3.2. Identification of CR Points

The SAR images used in the experiment are six PALSAR images acquired from December 2008 to December 2009. There are many houses and metal fences in the study area which have high reflectivity and perform to be lots of light spots in the image near the CR points. As a result the method using only RD model and artificial comparison can not satisfy the requirement of high identification accuracy. As discussed above, the DTA proposed here is used to identify the CR points in the six images respectively. In the experiment R is set to be 10 pixels while the threshold value of intensity being 1.0 dB. The algorithm is an iterative process and finally the location with the max value of γ_k is determined to be the final CR point.

With use of the method discussed, the 11 CR points' final locations are determined in the six images, respectively. The final performance of the detected CR points is shown in Figure 6. It can be obviously seen that the CR points detected are much brighter than the environment. With CR10 being destroyed accidentally during the highway construction, 11 CR's accurate row and column information are determined. Table 1 lists the exact row and column information determined with RD model inversion and DTA. It can be seen that DTA corrected and improved the column information of each CR point with max value of 4 pixels at CR 1 and min value of 1 pixel at CR 3.

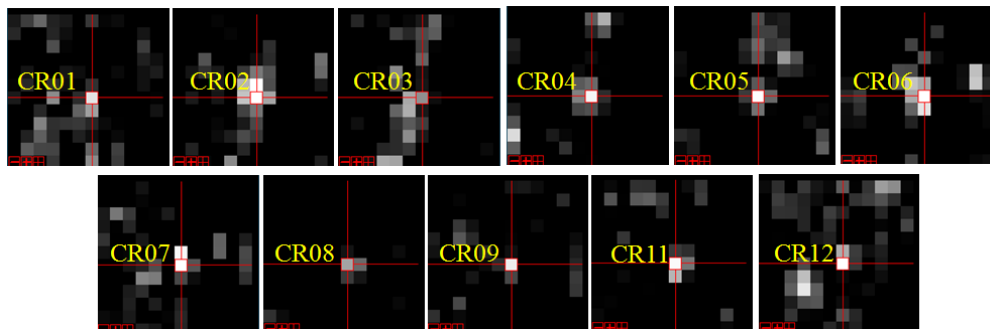


Figure 6. Detail of CR Points in Master Image

Table 1. SAR Coordinates of CR Points in Master Image Determined with RD Inversion and DTA

Index of CR	RD inversion		DTA	
	row	column	row	column
cr01	3840	5160	3840	5156
cr02	3868	5160	3868	5157
cr03	3913	5112	3913	5111
cr04	3930	5100	3930	5096
cr05	4650	4468	4650	4465
cr06	4763	4384	4763	4380
cr07	4782	4376	4782	4373
cr08	4832	4340	4832	4338
cr09	5455	4120	5455	4117
cr11	5532	4040	5532	4038
cr12	5398	4152	5398	4150

3.3. Validation

The reference distances between each two specified CR points in different SAR images need to be accordant. Due to this, we calculated the reference distances between each neighbored two of the 11 CRs in all the six images. In order to test if the reference distances in each slave image is consistent with that of the master image, we subtracted the reference distances in the master image from each of the five slave images and compared them in order to validate the identification accuracy of DTA. The comparison results including distances differences along both attitude and range direction is shown in Figure 7. From the comparison results we find that all the reference distances differences varied below 4m. According to the resolution of the six SAR images, the reference distances differences are all less than 1 pixel except the distance between CR07 and CR08 which is a little more than 1 pixel. This confirms that the accuracy of DTA identification is about 1 pixel. It proved that the CR locations determined with the new method is accurate and reliable.

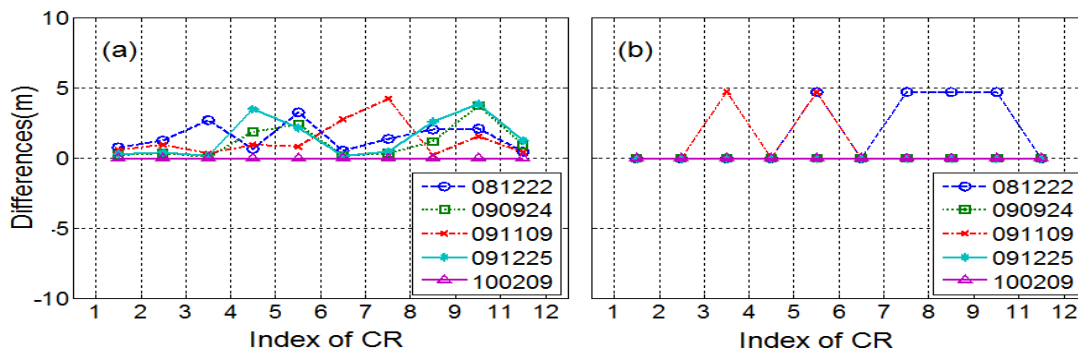


Figure 7. Differences of each Neighbored CRs' Distance in Five Slave Images Reference to that in the Master Image (a: Along the Attitude Direction, b: Along the Range Direction)

4. Conclusions

In this paper, a new method to identify the CR points is proposed, which uses Double Thresholding Algorithm (DTA) taking the intensity threshold value as initial criterion while the correlation coefficient as the final criterion. The method is applied successfully to identify the 11 CR points' locations installed along a highway and obtain their row and column information. The results show that the method proposed can be applied in the area where lots of lightspots exist near the CR points due to the severe environment. In this condition the traditional method based on RD model and visual check may lose effectiveness. The new method will not be limited to the circumstance and can avoid the artificial error during the personal visual check and comparison.

In order to validate the algorithm proposed, comparison of reference distances between each two specified CR points in different SAR images has been carried out. The comparison results show that the identification accuracy is about 1 pixel, so it can be concluded that the method presented in the paper is accurate and reliable. It can be applied to assist the CRInSAR algorithm in the ground deformation monitoring of highway. The future study will be focused on the application of DTA with CRInSAR algorithm to inverse the time series ground deformation of highway in Hunan province.

Acknowledgements

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