The Technology of Moving Target Detection and Tracking Based on Sequential SAR Image

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Abstract. Although the multi-channel SAR GMTI technology can be used in ground moving target detection, but only can get trace point of the ground moving target, the ground moving target tracking and track reconstruction can’t be achieved. This article presents a new method of ground moving target detection and tracking which is based on sequence SAR images. Firstly, the moving target detection and velocity estimation can be realized using the method of multi-channel processing. Secondly, the location of moving target can be estimated accurately using a high accuracy target location method based on knowledge-aid. The method uses the matching and target tracking technique based on sequential SAR images to realize the tracking and track reconstruction of moving target. Next, the image reference locking technology is used to achieve accurate image registration for a series of sequential SAR images obtained. Finally, the moving target can be tracked. The results of measured data shows the validity of the presented method.

1. Introduction
Multi-channel Synthetic Aperture Radar has two-dimensional high-resolution imaging ability in case of all-weather time, at the same time, it has the ability of detection, imaging and location of the moving target, that is means Ground Moving Target Indication(GMTI). Many scientific research institutions in China have carried out research and experiments on SAR-GMTI technology. Compared with single-channel SAR-GMTI system, multi-channel SAR-GMTI system can effectively utilize the information between channels, effectively suppress clutter and retain moving target information, and also can provide more freedom for velocity and location estimation of moving target[1].

Multi-channel SAR-GMTI system technology mainly includes Displaced Phase Center Antenna[2] (DPCA), Along-Track Interferometry[3] (ATI), Space Time Adaptive Processing[4-7] (STAP), and so on. However, the above processing technologies based on SAR-GMTI, unless the use of spotlight mode, with the platform movement can only obtain a single test result of the movement target, can not track the moving target. This article presents a new method of ground moving target detection and tracking based on sequence SAR images. Firstly, the moving target detection and velocity estimation can be realized using the method of multi-channel processing. Secondly, the location of moving target can be estimated accurately using a high accuracy SAR-GMTI target location method based on knowledge-aid[8]. The method uses the matching and target tracking technique based on sequential SAR images to realize the tracking and track reconstruction of moving target. Next, the image reference locking technology is used to achieve accurate image registration for a series of sequential SAR images obtained. Finally, the moving target can be tracked.
In the paper, the introduction is in Section I, the method of ground moving target detection and velocity estimation is presented in Section II, a high accuracy SAR-GMTI target location method based on knowledge-aid is reviewed in Section III. The proposed method of ground moving target detection and tracking based on sequence SAR images is discussed in Section IV, and results on real data are shown in Section V.

2. Moving Target Velocity Vector Estimation

The geometrical relation of ground moving target and radar platform is shown in Figure 1. Where, $v_a$ is velocity of the platform, $t$ is slow time of azimuth, $P$ is ground moving target whose coordinate is $(x_0, y_0, 0)$, $v_r$, $v_y$, and $v_x$ is radial velocity, range velocity and azimuth velocity of target respectively. $A, B, C$ is the phase center of three channels.

![Figure 1. Observation Model of three-channel SAR-GMTI](image)

Take the three-channel ATI method as an example, the process of single-channel SAR imaging, channel registration, and clutter suppression and target detection is omitted. Ground moving target can be detected by CFAR in the range-Doppler domain. By the dissolved images which are obtained through A-B and B-C, the interferometry phase of the target can be obtained by means of interferometry:

$$\Delta \varphi = \frac{2 \pi}{\lambda} 2v_r \frac{d}{v_a}$$  \hspace{1cm} (1)

In turn, the radial velocity and azimuth velocity of the moving target can be derived:

$$v_r = \frac{\Delta \varphi \lambda v_a}{4\pi d}$$  \hspace{1cm} (2)

$$v_y = \frac{\Delta \varphi \lambda v_a R_0}{4\pi dy_0}$$  \hspace{1cm} (3)

Thus the position offset of the azimuth is:

$$\Delta x = \frac{R_0 v_y}{v_a}$$  \hspace{1cm} (4)

The azimuth velocity of the moving target can cause the defocusing of target. The method of estimating the azimuth velocity of the moving target can be divided into two categories. One is the method of estimating Doppler frequency Rate of the target, and the other is to set up different matching functions, and solve the azimuth velocity by evaluation the target focus effect. Using the first type method as an example, Doppler frequency rate $\hat{k}_a$ is estimated of the moving target. The relationship of moving target azimuth velocity and Doppler frequency rate is:
The azimuth velocity of target can be estimated:

\[
v_a = v_u - \sqrt{\hat{k}_a R_0 \lambda / 2 - v_y^2}
\]  

(6)

3. Technology of high accuracy SAR-GMTI target location based on knowledge-aid

Once the radial and azimuth velocity of the ground moving target estimated, the velocity vector for the target can be obtained as:

\[
\vec{v} = \hat{v}_y + i \hat{v}_x = \sqrt{\hat{v}_y^2 + \hat{v}_x^2} \left( \cos \theta + i \sin \theta \right)
\]  

(7)

Where, \( \hat{v}_y \) and \( \hat{v}_x \) are the estimation value of radial and azimuth velocity respectively. \( \theta \) is the angle between the velocity vector and the radial velocity direction. The road information on the SAR image can be extracted by using statistical-based boundary detection method. By matching the moving target velocity vector to the direction of the road, the positioning accuracy of the target can be greatly improved.

4. Sequential SAR image moving target detection and tracking

In the above Section, although the moving target is be detected and relocated on the road, but this time it's just one point information for the target, the track of target can’t be obtained when the system works in strip-map SAR. The track information of the moving target is more important for track prediction and target intent judgment.

Further analysis, the resolution of SAR-GMTI system is usually chosen to match the target size. Because the target size is mostly meter or ten meters, the resolution is set to 1~5meters in most cases. In this case, the synthetic aperture time is short, on the other hand, the system also has the function of high-resolution SAR imaging, so the emission of the azimuth beam width is relatively wide. The above conditions provide the possibility for the GMTI trace based on sequential SAR images.

Set the azimuth aperture width of the transmit antenna is \( D \), the equivalent azimuth beam width is \( \theta_{adb} = K \lambda / D \) ( \( K \) is the scale factor). The deramp imaging algorithm with a shorter synthetic aperture time is usually selected in order to reduce the effect of range walking due to the target movement. Suppose no data overlaps when two adjacent images are imaged and the accumulate pulse number according to the synthetic aperture time is \( Num_{single} \), then the number of sequential SAR images available in the entire beam coverage range is:

\[
n = \frac{Num}{Num_{single}} = \frac{Ls / V_a \cdot PRF}{Num_{single}} = \frac{R_0 K \lambda}{DV_a \cdot PRF}
\]  

(8)

Where \( Num \) is total pulse number in the entire beam coverage range, \( Ls \) is the length of synthetic aperture according to the entire beam coverage range, \( R_0 \) is distance, \( PRF \) is pulse repeat frequency. After the moving target detection and positioning processing described in Section I and II of the sequential SAR images obtained in turn, the moving target point information in each sequential SAR images can be obtained. On this basis, it is necessary to match the sequential SAR images and to correlate the moving target information in each image.

4.1. Sequential SAR Image Tracking Locking Technology

We use the sequential SAR image registration method based on image tracking locking technology, which is based on the R-D model[9]. The R-D model consists of three equations:
\[
\begin{align*}
\vec{R}_e &= \vec{R}_g - \vec{R}_0 \\
\mathbf{f}_{DC} &= -\frac{2}{\lambda R} (\vec{V}_e - \vec{V}_s) \cdot (\vec{R}_e - \vec{R}_o) \\
x_i^2 + y_i^2 + \frac{z_i^2}{(R_e + h)^2} + \frac{1}{R_p^2} &= 1
\end{align*}
\]

The three equations are distance equation, Doppler equation and Earth data model. \( h \) is the \( P \)-to-ground line distance on the ground. \( \vec{R}_e = (x_i, y_i, z_i) \) is the coordinates of the \( P \)-point.

The sequential SAR image tracking locking technology consists of two main steps:

1. Based on the first image, suppose the platform center is the origin, according to the radar platform's longitude and latitude, the operating distance, Doppler and the track angle and other parameters, the longitude and latitude of the reference point in the SAR image can be obtained.

2. According to the longitude and latitude of the reference point in the first image, the corresponding points can be found in other sequential SAR images. Then, with the point as the sequence image center, intercept the corresponding part of the first image.

The process is shown in the Figure 2.

The registration in the processing process includes the conversion between multiple coordinate systems: Image plane coordinate system->Flight coordinate system, Flight coordinate system->Northeast Sky coordinate system, Northeast Sky coordinate system->Center-to-earth space right-angel coordinate system, Center-to-earth space right-angel coordinate system->Space geodesy coordinate system. For the SAR-GMTI system of strip mode, there is no large angel rotation between the sequential SAR images obtained, so the conversion of the above coordinate system can be simplified.
4.2. Moving target traces/track association processing technology

(1) Pre-processing of trace points of moving target
There is a strong correlation between the real target echoes in the sequence SAR images, but the false alarm is not. Therefore this feature can be used to distinguish between real target and false alarms. That means, the information of the detected moving target, such as amplitude, phase, distance and Doppler, can be used to be conditions of judgment.

(2) Joint correlation processing of trace points and track
The joint correlation processing of trace points and track is optimal correlation for established tracks and newly detected trace points, in order to minimize the track splitting caused by leakage and the trace error caused by miscorrelation. These are not covered in detail in this article.

5. Real Measurement
In order to test the effectiveness of proposed processing, result based on real data has been provided. The data was obtained by four-channel SAR system mounted on an airborne platform. The velocity of platform is 120m/s. In the scene, there are three cooperative moving targets on a road perpendicular to the direction of the aircraft. The targets travel at a certain distance, with the same radial speed and the speed is 3m/s.

The resolution of SAR image is 3meters. According to the equation (8), there are 14 sequence SAR images can be obtained. Figure 3 shows four of these sequence SAR images, with serial numbers 1, 4, 7, 10. After imaging, the target detection and positioning method introduced in Section 1 and 2 is carried out, and three targets can be detected effectively in each image, which are represented by red, green and yellow dots respectively shown in Figure 3. The estimated results of the moving target parameters are listed in Table 1. The road intersection in the sequence SAR image with the serial number 4 is selected to be the reference point, which is shown in Figure 3(b) with a white dot. Using the method proposed in Section 3 for sequence SAR image tracking locking, we can effectively track the corresponding position of the reference point in the sequence images, which are also shown in Figure with white dots. The scene that intercepts the same area of the sequential SAR images sequence after the track lock is drawn in Figure 4, where the size is 550*400 pixels. The position of the moving targets moves on the road due to the differences in sequential SAR image imaging times. Clear tracks can be obtained after all detected targets in the sequential SAR image are processed using the method described in Section 3. The result is shown in Figure 4, where the red, green and yellow lines are three moving target tracks respectively.

Figure 3. The result of sequential SAR imaging and ground moving target detection(The big white dot is reference point, red, green and yellow dot is the three moving target detected respectively)

Figure 4. The result of track reconstruction of moving target(red, green and yellow dot is the three moving target detected respectively)
Table 1. The estimated results of the moving target parameters.

| Serial number | Velocity (m/s) | Range position | Azimuth position |
|---------------|----------------|----------------|-----------------|
|               | T1  | T2  | T3  | T1  | T2  | T3  | T1  | T2  | T3  |
| 1             | 2.96| 2.87| 2.97| 209 | 237 | 311 | 521 | 526 | 525 |
| 2             | 3.01| 2.95| 3.02| 210 | 237 | 312 | 521 | 526 | 525 |
| 3             | 2.99| 2.89| 2.92| 211 | 238 | 313 | 521 | 526 | 525 |
| 4             | 2.96| 2.94| 2.93| 212 | 239 | 315 | 521 | 526 | 525 |
| 5             | 2.91| 2.98| 2.96| 213 | 240 | 317 | 521 | 526 | 525 |
| 6             | 3.02| 2.98| 2.96| 214 | 241 | 318 | 521 | 526 | 525 |
| 7             | 3.05| 3.01| 2.94| 215 | 242 | 319 | 521 | 526 | 525 |
| 8             | 2.93| 3.02| 3.05| 215 | 243 | 321 | 521 | 526 | 525 |
| 9             | 2.94| 2.92| 2.98| 215 | 244 | 322 | 521 | 526 | 525 |
| 10            | 2.96| 2.98| 2.96| 216 | 245 | 323 | 521 | 526 | 525 |
| 11            | 3.01| 3.01| 2.94| 217 | 246 | 324 | 521 | 526 | 525 |
| 12            | 2.94| 2.93| 2.96| 217 | 247 | 325 | 521 | 526 | 525 |
| 13            | 2.96| 2.98| 2.96| 218 | 248 | 327 | 521 | 526 | 525 |
| 14            | 2.91| 2.98| 2.96| 219 | 250 | 329 | 521 | 526 | 525 |

6. Conclusion
Aiming at the problem which is that multi-channel SAR-GMTI technology can only get trace point of the moving target, this article presents a new method of ground moving target detection and tracking based on sequential SAR images. The method uses the matching and target tracking technique based on sequential SAR images to realize the tracking and track reconstruction of moving target. The results of measured data show the validity of the presented method.

References
[1] Zhang Sheng, Sun Guang-Cai, Multi-channel Synthetic Aperture Radar-Ground Moving Target Indication High-accuracy Focusing and Positioning Using Instantaneous Interferometry, Journal of Electronics & Information Technology, 2015, Vol.37(7), pp.1729-1735.
[2] Bao Zheng, Liao Guisheng, et al, Adaptive Spatial-temporal Processing for Airborne Radars[J].Chinese Journal Electronics, 1993, (1):1-7.
[3] Stephen J Fmsier.Dual-beam interferometry for ocean surface current vector mapping[J].IEEE Transaction on GRS, 2001, 8(2):401-414.
[4] Liao Gnisheng, Bao Zheng, Xu Zhiyong,A framework of rank-reduced space-time adaptive processing for airborne radar and its applications[J].Science in China SeriesE, 1997, 40(5):505-512.(in Chinese)
[5] Wang H S C.Main lobe clutter cancellation by DPCA for space-based radars[A].Aerospace Applications Conference [c].Digest, IEEE, 1991.1-128.
[6] R Klemm.Principles of Space-Time Adaptive Processing[M].London, U K:Inst Elect Eng, 2002.
[7] William L, Melvin, et al, Assessment of multi-channel airborne radar measurements for analysis and design of space-time processing architectures and algorithms[A].IEEE National Radar Conference [C].Ann Arbor, Michigan:IEEE, 1996.130-135.
[8] LIU Ying, NIE Xin, LING Kai, Technology of High Accuracy SAR-GMTI Target Location Based on Knowledge-aid[J], Modern Radar, 2017,7:25-27.
[9] Curlander J C. Location of pixels in space borne SAR imagery[J]. IEEE Transactions on Geosciences and Remote Sensing, 1982, 20(3): 359-364.