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AN INTEGRATED METHOD FOR REFOCUSING OF MOVING TARGETS IN SPOTLIGHT SAR

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Abstract

A new target-refocusing technique based-on re-centering phase computation of previously recorded moving target raw data is implemented to the Spotlight SAR data in order to obtain refocused moving targets. The technique is tested on the integrated simulated data; background real spotlight SAR Raw data with the synthetically generated data domes of civilian moving targets. First Polar format Algorithm is applied to detect and estimate the speed of ground-moving targets on the integrated raw data. At the next step, re-organize the integrated raw data by selecting and arranging target focusing center with a new technique based on re-centering phase computation to each moving target speed. At the third step re-organize the raw data by re-centering the phase computation to each moving target location. Finally, Polar Format Algorithm is applied to each reorganized raw data to obtain highly focused moving targets individually.
Keywords: Ground moving target, spotlight SAR, Refocusing, phase correction, Polar Format Algorithm

SPOTLIGHT YAR VERİLERİNDE HAREKETLİ HEDEFLERİN YENİDEN ODAKLANMASI İÇİN ENTEGRE BİR YÖNTEM

Öz

Spotlight YAR verilerinde hareketli hedeflerin yeniden odaklanması için merkeze göre faz düzeltmesine dayalı yeni bir hedef odaklama tekniği uygulanmıştır. Bu teknik, arka plan gerçek spotlight YAR verisi ile sentetik olarak oluşturulmuş hareketli sivil araç veri kubbeleri entegre edilerek denenmiştir. Entegre edilmiş ham veride hareketli hedef tespiti ve hız kestirimi için öncelikli olarak Polar Format Algoritması uygulanır. İkinci adımda herbir hareketli hedef hızı için yeni bir merkez faz hesaplama yöntemi ile entegre edilmiş ham verinin faz bilgisi yeniden düzenlenir. Sonraki adımda yeniden düzenlenmiş bu ham veriye Polar Format Algoritması uygulanarak hedefin yeri tespit edilir ve görüntü merkezine göre hesaplanan faz düzeltmesi belirlenerek, ham verinin faz bilgisi yeniden düzenlenir. Son adımda Polar Format Algoritması tekrar uygulanarak yüksek çözünürlükle odaklanmış hedefler ayrı ayrı elde edilir.
Anahtar Kelimeler: Hareketli hedef, Spotlight YAR, Yeniden odaklama, Faz Düzeltmesi, Polar Format Algoritması.

1. Introduction

The goal of the research is to identify the best method for providing Ground Moving Targets (GMT) for Spotlight SAR systems that are highly focused. The shifting of moving targets in SAR images results from their motion in the range direction. Target smearing results from variations in the resulting azimuth chirp rate and a resulting miss-match, which are specifically caused by an along track (a.t.) target velocity component. We don't suggest a novel method for target detection or speed estimate in this research. However, the need for detecting moving targets and estimating their velocities appears in many SAR applications, Dias and Marques (2003), Lv et. al (2016), Fienup (2001), Yang et. al (2015) and Sjogren et. al (2012). Zhu et. al (2011) propose a new imaging approach without a priori knowledge of the target motion parameters In, Cristallini et. al (2009) a moving target detection and high-resolution focusing scheme has been presented: the detection of moving targets is made via a bank of chirp scaling

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algorithms (CSAs), each one matched to a different along-track target velocity component, thus providing high resolution image of the target. The choice of the CSA as focusing technique has also come with the computational load, Raney et. al (1994). A different and computationally more efficient GMTI technique based on Change Detection (CD) is proposed in, Pastina et. al (2008): a sequence of SAR images is obtained by dividing the synthetic aperture time into several intervals, each providing sub-image. Since moving objects appear at different positions in different images, change detection techniques can be applied to detect the moving targets. These algorithms are also tested with the remotely sensed data such as COSMO-SkyMed spotlight SAR data, Pastina et. al (2011) and improved the target focusing quality by refocusing method used in SAR, Sjugren et. al (2012).

Different from Sjugren et. al (2012), instead of dividing the image into sub-images and do the unwrapping, sub-patch focusing algorithm is proposed to acquire highly focused target in Papila et. al (2015). Ruizhi et. al (2019) also proposed a zoom-in PFA where image scene is bounded to a small region near the reference point to produce a refocused image. Mao et. al (2009) shows that defocusing effect occurs only in the along-track direction while Yang and Zhang (2015) shows the azimuth shift is proportional to the target velocity at the range direction. In Papila et. al (2015), it is showed that the defocused stationary targets located away from the scene center can be refocused by a phase recalculation at the demodulation step. In our proposed algorithm all those three defocusing effects can be handled by a phase correction process for each moving target center which is applied at the slow time domain.

Proposed Algorithm Steps:

- Find the Moving Targets and Parameters
- Re-organize the raw data with the target velocity parameters
- Select and Arrange Target Focusing Center
- Re-organize the raw data
- Highly Focusing Target Image

Polar format algorithm is implemented to the real Spotlight SAR background data and the simulated moving targets to evaluate the proposed method. Mathematics behind the PFA are explained in Deming et. al (2015).

2. Mathematical Model Of Moving Target In Polar Format Spotlight Data

For a spotlight SAR system using a linear FM chirp signal with α chirp rate and Tp pulse width, the signal phase received from a point target for any slow time interval in the receiving time window rect((t-td)/Tp) is

$$\emptyset(t) = \omega_0 (t - t_d) + \pi\alpha (t - t_d)^2 \tag{1}$$

Where td is the round-trip time delay between the antenna and the point target. Assuming the reference range of the global scene center is R0 and the corresponding round trip time delay is t0 after demodulating the received signal with respect to the reference range, the phase of the IF signal is

$$\emptyset_{IF}(t) = \omega_0 (t_0 - t_d) + 2\pi\alpha (t_0 - t_d) - \pi\alpha (t_0^2 - t_d^2) \tag{2}$$

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In Spotlight SAR processing for the moving target case SAR image always appears defocused and located at false location; this can be described as multiplicative error. 2-D interpolation step of the PFA can be separable by 1-D range and azimuth sampling. First step is range sampling, by using Taylor expansion and ignoring cubic and higher order terms. Azimuth resampling is a range frequency dependent slow time scaling procedure, can be interpreted with a keystone transform (azimuth interpolation) which corrects the linear range walk of moving target (Range cell migration).

The IF signal described in Eqn. (2) is then azimuth compressed to form the SAR image. In the demodulation step, a phase recalculation process for each moving target center is applied to the whole raw data on our desired method.

The proposed method can be described with the following steps:

- Step 1: Find all moving targets with their velocities and moving direction.
- Step 2: Determine the center of each moving target and corresponding round trip time delay (ti for ith moving target)
- Step 3: Obtain demodulated signal individually for each moving target by mixing the IF signal previously obtained for global scene center and the reference signal calculated by using the ti time delay.
- Step 4: After mixing and low pass filtering, the phase of the demodulated signal for ith moving target is

$$\emptyset'_{IF}(t) = \omega_0 (t_i - t_0) + 2\pi\alpha (t_i - t_0) - \pi\alpha (t_i^2 - t_0^2) \quad (3)$$

- Step 5: Obtain highly focused SAR image for each moving target

3. Movıng Target Refocusıng Algorıthm

In this algorithm we propose a method to simulate a background speckled scene with moving targets in the hybrid domain. Figure 1 shows the flowchart of the proposed method for the simulation of moving targets in the background. Volumetric Gotcha dataset AFRL (2007) is used is speckled SAR complex image of the background. Civilian vehicles dataset Ohio State University (2010) is used to model the moving targets based on Zaharris and Saghri (2007) simulation method. Performance of the proposed algorithm is tested by using Matlab simulation. Integration of the two dataset in time domain is performed based on the Rahmanizadeh and Amini (2017) model. Once we the hybrid raw data, we perform the PFA to detect and estimate the velocities of the moving target. For a given target velocities we perform the PFA once again to eliminate the defocusing effects due to target velocities. But there is still defocusing effect at the target due to the phase difference between the target center and the scene center. This phase effect can also be compensate by determining the target center and re-organize the raw data following a final PFA which leads us to the highly focused image for a given target. The algorithm continues until the final target is highly focused. Table 1 shows the SAR parameters to be used to at the Matlab simulation for the proposed algorithm.

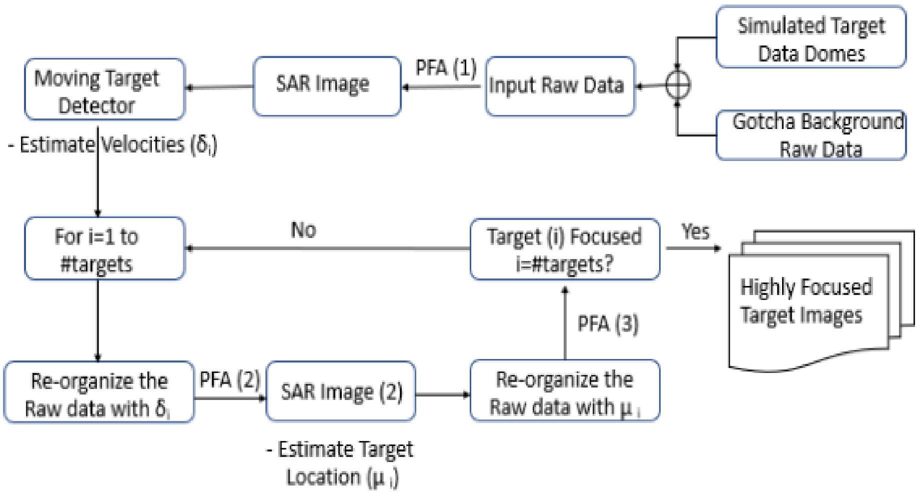

Figure 1. Schematic Sketch of the Proposed Algorithm

Table 1. SAR simulation parameters to be used at PFA for the proposed method

	SAR Parameters
Carrier Frequency	9.28 GHz
Pulse Duration	1.34759 µs
Radar PRF	250
Sampling Frequency	171.2 MHz
Chirprate	1.5x1014 Hz/s
Range distance	10182 m
Platform Velocity	378 m/s

4. Datasets

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4.1. Gotcha Volumetric Dataset

The Gotcha dataset operates at X-band with 640MHZ Bandwidth. 8 different elevation angle full azimuth coverage (360 degree) with a fixed range resolution 0.24m. In order to make the pixel resolution square we choose the azimuth resolution as 0.23m which corresponds to 4° azimuth aperture (0.0697 radian). Range distance is 10182m, azimuth aperture length is 709m. Carrier frequency is 9.28GHz. At the end we had 424 Range and 469 Pulse with 100x100m image size SAR image. Figure 2 shows processing result of the Gotcha dataset by using PFA.

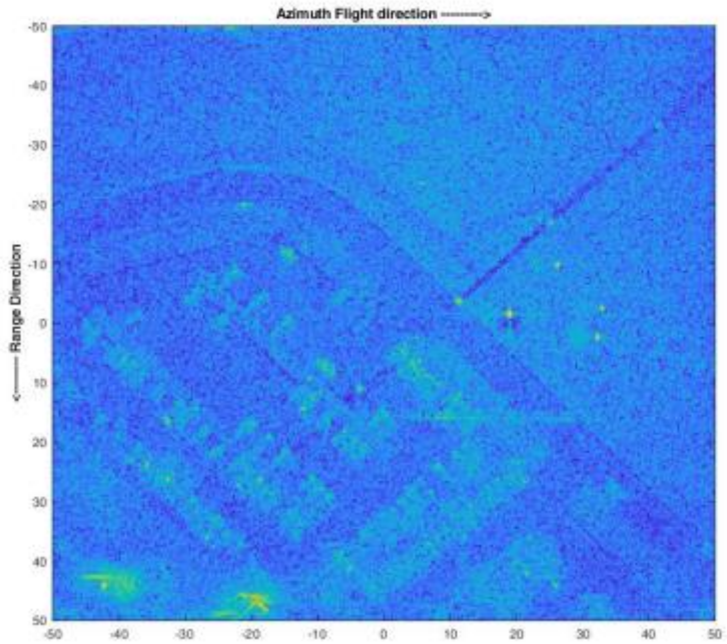

Figure 2. Polar Format Algorithm image using Gotcha volumetric dataset

4.2. Civilian Vehicles Dataset

Honda and Toyota civilian vehicles models are used as a moving targets. In order have the same azimuth and range resolution with the background Gotcha dataset, the civilians vehicles are modeled with using lower number of scatterers than the original model. Toyota Civilian vehicle is modeled with 234 point scatterers while the Honda Civilian vehicle is modeled with 182 point scaterers. Figure 3 shows the full resolution of the civilian vehicles both located at the scenario using the PFA.

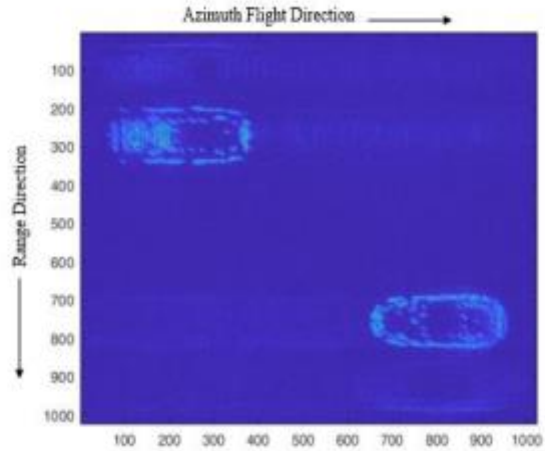

Figure 3. PFA image of Honda and Toyota CAD model stationary targets

4.3. Integrated Test Dataset

Once the background and the target raw data with the same resolution is present at time domain, we integrated the two datasets in time domain. Stationary civilian vehicles are shown at the Figure 4 over the Gotcha dataset. Honda civilian vehicle is located on the upper left side at the scene while the Toyota civilian vehicle is located lower right of the scene.

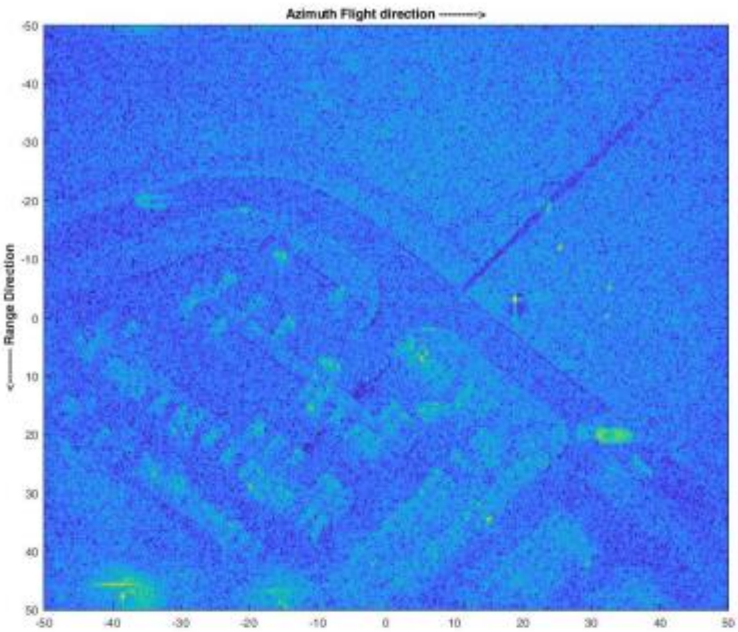

Figure 4. Integrated Test Dataset; Toyota and Honda CAD model stationary targets are located at the scenario

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5. FOCUSING OF MOVING TARGETS IN THE INTEGRATED DATASET

Both Civilian vehicle Honda and Toyota is integrated with the Volumetric Gotcha Data in Time Domain. Target location is unknown. First, we determine the velocity of the targets and we don't use the target location to focus the target at the first step. Then we use the phase correction to compensate the moving target phase according to the scene center. In order to focus the target in original location, we move the scene center of the image with the same velocity of the target. So, the target is focused at its original location. Once the target location is determined we can move the target to the scene center to have a more focused target. Assuming both vehicles are moving in constant velocity; the Toyota vehicle is moving with -8m/s in azimuth and 1m/s in range direction while the Honda vehicle is moving with 5m/s in azimuth direction and -1m/s in range direction. The moving target scenario is shown at Figure5. Figure 6 shows the focused Honda vehicle at the original location while Figure 7 shows the processing result of the PFA for the focused Toyota vehicle at its original location.

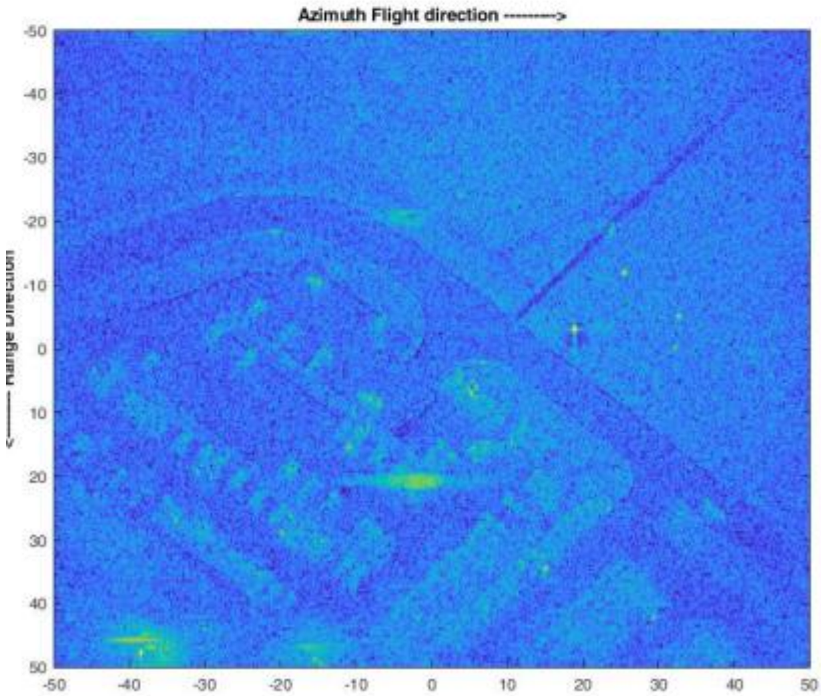

Figure 5. PFA result for the moving Toyota and Honda vehicles at the integrated dataset

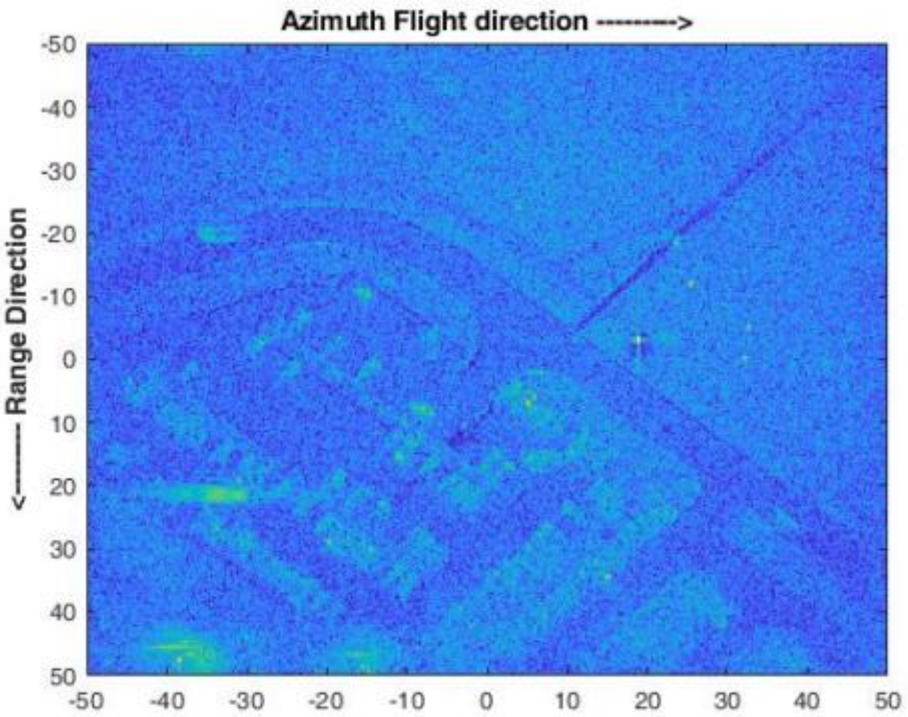

Figure 6. Honda with 5m/s azimuth and -1m/s range velocity is focused at the original location

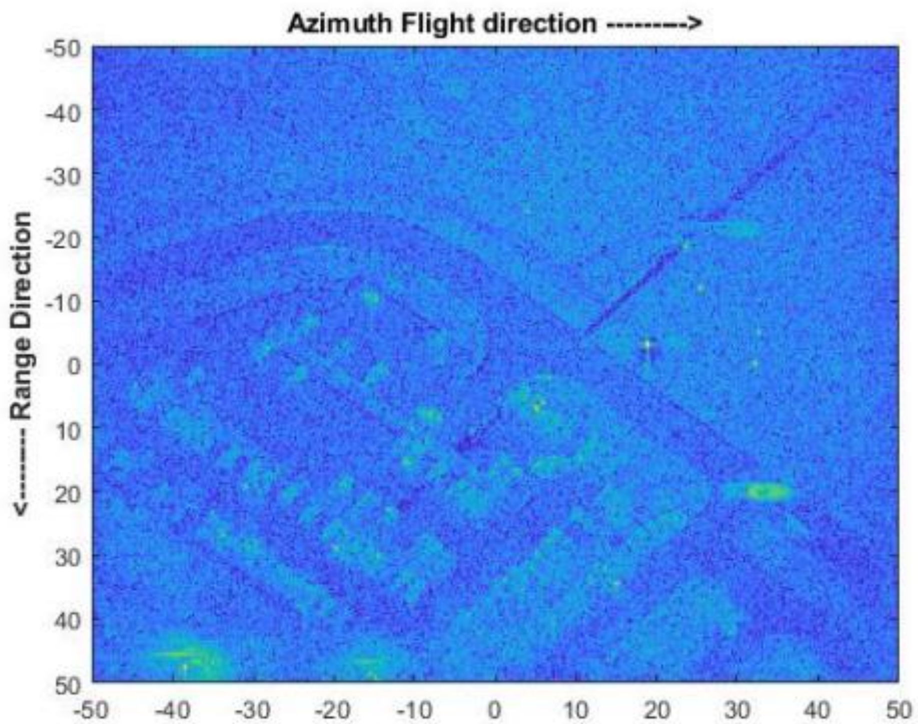

Figure 7. Toyota with -8m/s azimuth - 1m/s range velocity is focused at the original location

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5.1. Quality Evaluation of the proposed Algorithm

The peak signal-to-noise ratio (PSNR) are commonly used to evaluate SAR focusing algorithm quality. The PSNR is adopted to calculate the squared intensity difference between the moving target focused image with the stationary target unfocused image and is associated with the quantized gray level of the SAR image.

$$PSNR = 10 \log_{10} \frac{Q^2 x M x N}{\sum_{i=1}^{M} \sum_{j=1}^{N} (f^s(i,j) - f(i,j))^2} \quad (4)$$

Where $f\ s\ (i,j)$ is the stationary target unfocused image and $f(i,j)$ is the focused final moving target image. M, N are the length and width of the image and Q represents the gray level of the image (Q=255) The range velocity causes the azimuth displacement and inaccurate range estimation leads big PSNR values since the image positions are located at totally different area of the scene. So, testing the range velocity estimation error wouldn't be meaningful for performing the focusing algorithm. First, we run the algorithm while both vehicles are stationary and final image is focused according to the scene center (Figure 5.). Toyota vehicle with -8m/s azimuth velocity is used to test the target velocity estimation accuracy effect over the proposed algorithm. Once we run the algorithm for a given estimation results to eliminate the defocusing effect; the Final image is compared with the stationary target image result. Figure 6. shows the focused target image with a 100% target velocity estimation accuracy. Figure 7. shows the focused target image where the azimuth velocity is estimated as 7.6m/s (95%). The final Figure 8. shows the focused target image where the azimuth velocity is estimated as 7.2m/s (100%). PSNR values are shown at the table 2. for the different velocity estimation accuracies.

Table 2. Evaluation of the proposed focusing algorithm

	Azimuth 100% Acu	Azimuth. 95% Acu	Azimuth. 90% Acu.
PSNR (dB)	29.1 dB	25.4 dB	21.7

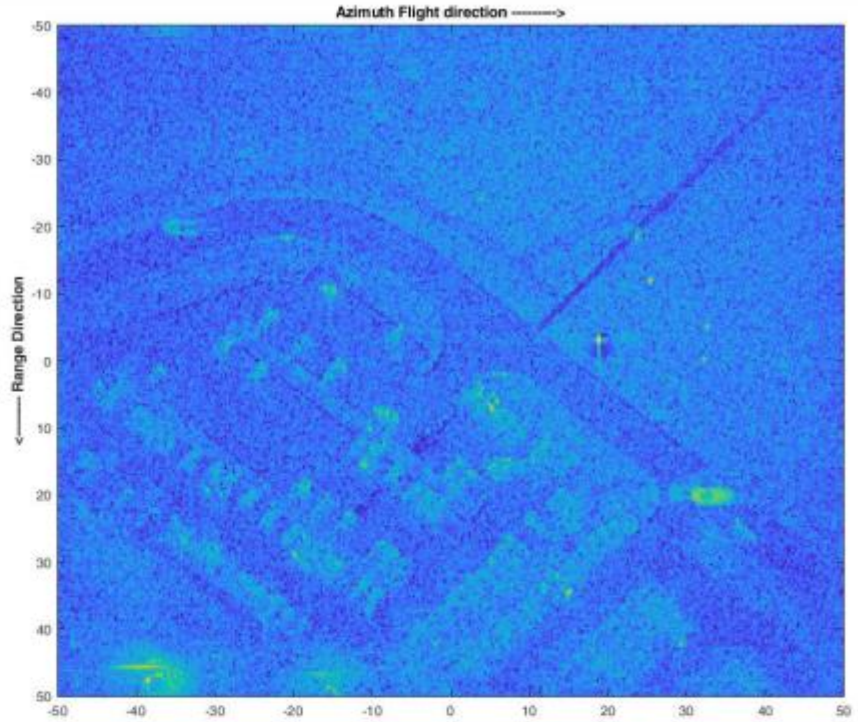

Figure 8. Stationary Honda and Toyota civilian vehicles focused according to scene center

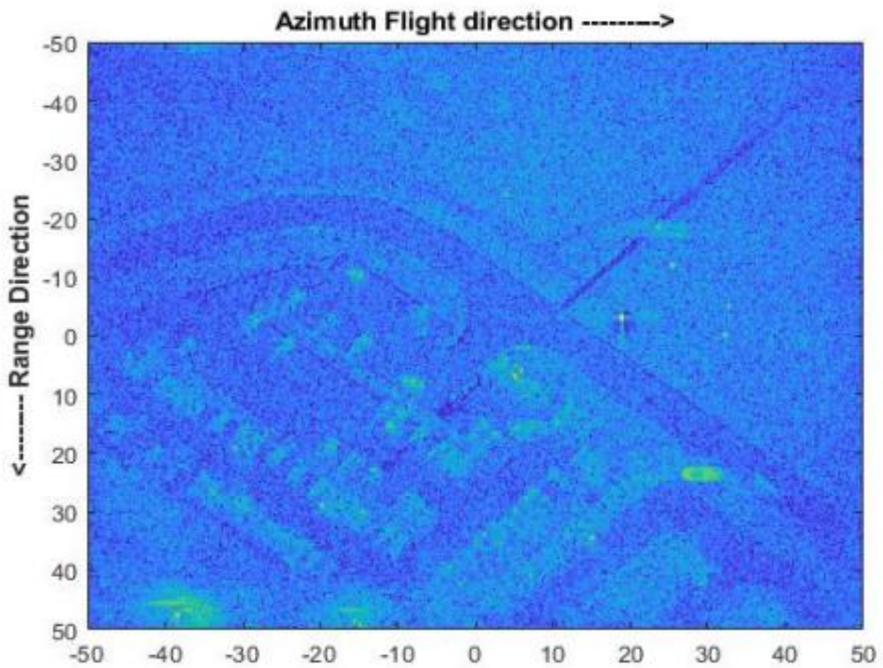

Figure 9. Focused Toyota vehicle (azimuth velocity estimation accuracy 100%) original location

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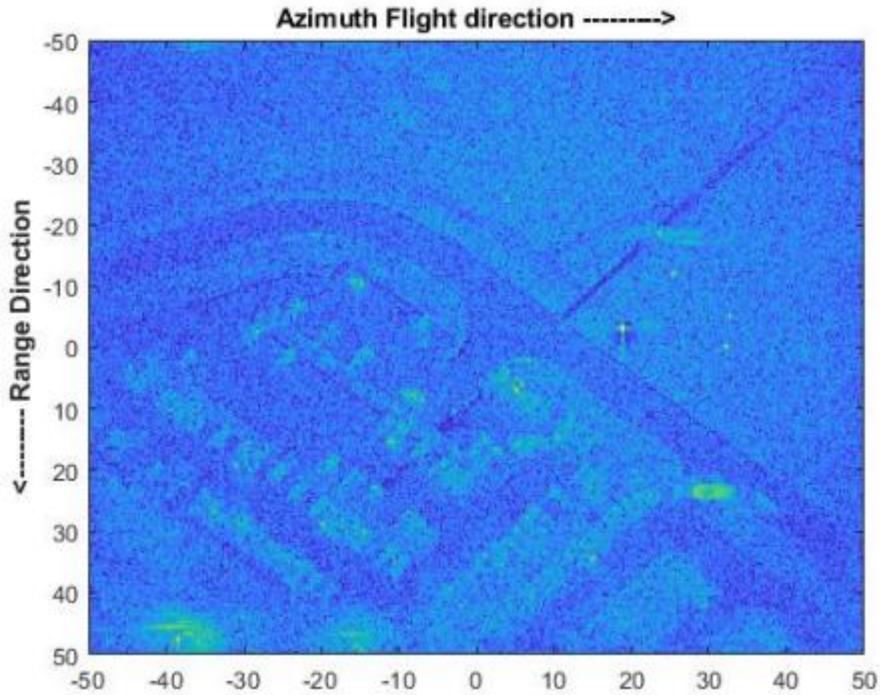

Figure 10. Focused Toyota vehicle (azimuth velocity estimation accuracy 95%) original location

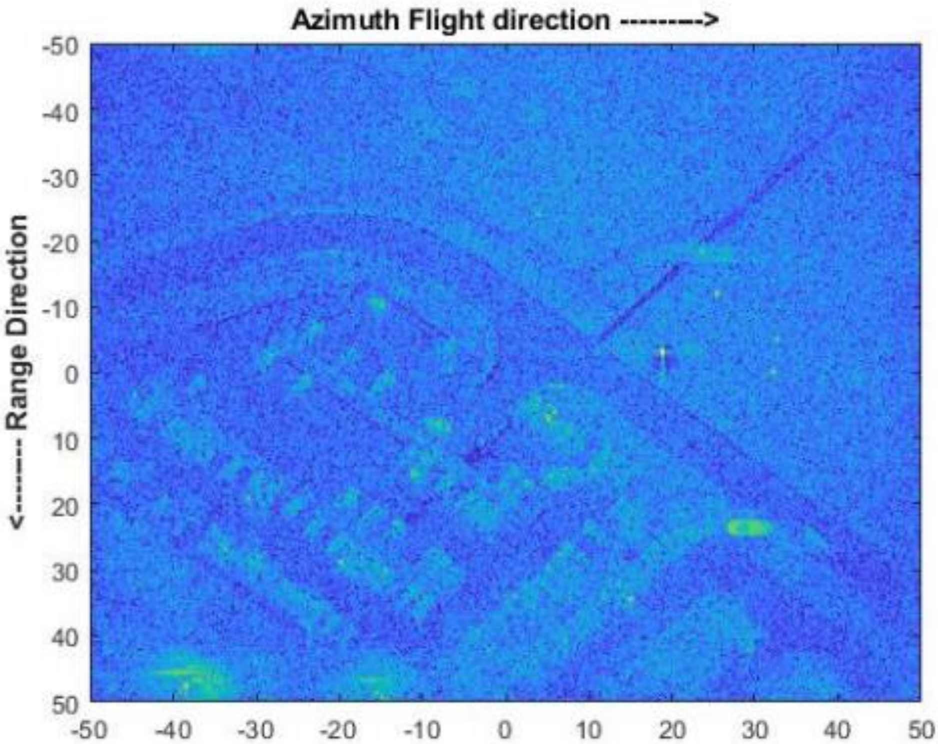

Figure 11. Focused Toyota vehicle (azimuth velocity estimation accuracy 90%) original location

6. Conclusion

Spotlight Synthetic Aperture Radar imaging techniques have an image quality feature that degrades as you move away from the focusing region. In particular, the presence of moving targets in the imaging region affects the quality of the entire image and makes it difficult to detect the moving target. In this study, a method for detecting moving targets only is proposed by performing the necessary correction (refocusing) on the raw radar data to detect the moving targets on the SAR images created with the collected raw radar data and after this detection to compensate for the motion feature. Proposed method is tested by using the targets with constant velocities. However, the algorithm is also capable of producing highly focused targets with the variable velocities and directions during collecting the raw data. Since the phase correction is applied at the slow time domain while re-organizing the raw data, newly calculated phase correction parameter can be applied even at every pulse for a new target velocity and direction. The proposed method has been tried for artificial moving target samples added to real radar data, and the distinguishable detection of moving targets has been achieved successfully.

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CONFLICT OF INTEREST

The authors must declare that they have any conflict of interest.

AUTHOR STATEMENT

The authors have to declare that if there is any ethical approval, consent to participate, consent for publication, availability of data and material, and code availability etc.

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