# Efficient Detection and Ground Mapping of Selected Moving Targets using SAR raw-data[*]

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## ABSTRACT

This work addresses moving targets detection and imaging using airborne SAR data. Targets are selected according to user-defined radial velocity and direction. The computational burden is drastically reduced because azimuth compression is done only for ranges with a positive moving target indication. Furthermore, the knowledge of the velocity sign allows to tune the detection and focusing of moving targets with higher SNR than the usual methods. Range migration is easily tackled because radial velocity is known, enabling the correct compression filter design.

## INTRODUCTION

Detection and identification of moving targets using SAR data is an active area of research. Several methods have been proposed to detect, image, and estimate moving targets trajectory parameters, in recent literature [1], [2], [3], [4], [5]. Basically they are supported on the azimuth signature Doppler shift and multilook techniques.

Herein we formalize the problem of moving targets in SAR imagery and propose a methodology to detect and image objects that move with a predefined radial velocity and direction.

To detect the presence of moving targets within a certain radial speed, a moving target indication (MTI) based on the expected Doppler shift is implemented. The clutter and moving targets that do not move within a certain velocity range are filtered out in the frequency domain. To reduce drastically the computational power required to compute the image, azimuth compression is done only for those ranges in which there is a positive MTI. Additionally, the knowledge of the velocity sign allows to tune the detection and focusing of moving targets. This methodology is able to both detect and ground mapping the targets of interest, showing good clutter cancellation.

This paper is organized as follows:

Section 2 considers the effects of moving targets on the received signal. The moving targets under consideration have Doppler shifts that are, in general, much smaller than the pulse bandwidth of a SAR, so Doppler shifts on range compression can be ignored.

Section 3 describes the proposed methodology to detect and image the targets of interest.

In section 4 simulation results are presented.

## STRIP-MAPPING SAR IN THE PRESENCE OF MOVING TARGETS

Fig. 1 shows a typical SAR geometry. As the radar travels at constant velocity in azimuth direction (navigation direction), short microwave pulses are transmited at regular intervals, and the corresponding echoes are recorded. Many pulses are transmitted during the time the platform takes to travel the footprint, i.e., the integration time. High resolution in azimuth is achieved by synthesizing a large aperture, exploiting the relative motion between the platform and the ground. If the targets are moving, the echoes become modified, carrying information about their motion parameters.

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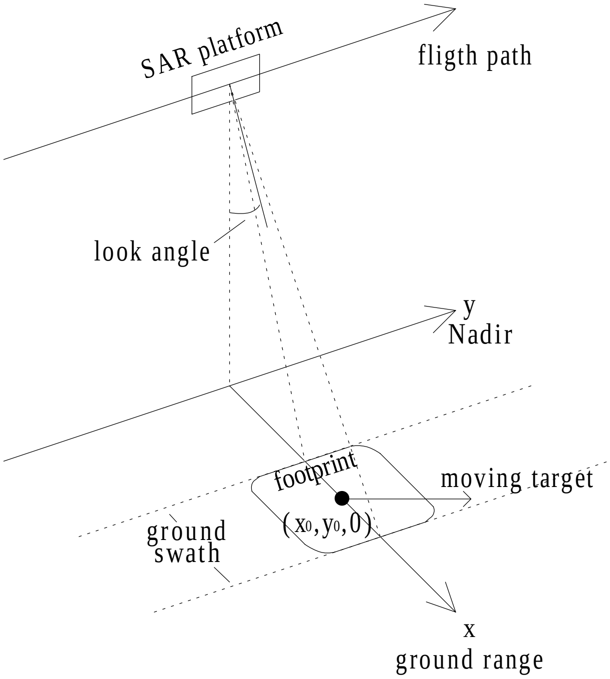

Figure 1: SAR scenario containing a moving target.

### Azimuth Signature Doppler Shift

Consider the stripmap SAR geometry in the presence of a moving target. At time $t$ the coordinates of the platform and the target are $(x,y,z) = (0,Vt,h)$ and $(x(t),y(t),0)$. The range distance between the target and the platform is, for a time $t$ given by

$$R(t) = \sqrt{(Vt-y)^2 + x^2 + h^2}. \tag{1}$$

Define $t_0$ as the time in which the target position is $(x_0,y_0,0)$, and assume that $Vt_0 = y_0$ (i.e., the distance between the platform and the target reaches its minimum). The Taylor series of $R(t)$ is

$$R(t) = R(t_0) + (t-t_0)\dot{R}(t_0) + \frac{(t-t_0)^2}{2}\ddot{R}(t_0) + ..., \tag{2}$$

where $\dot{R}(t) = \frac{dR}{dt}$ and $\ddot{R}(t) = \frac{d^2R}{dt^2}$. For our purposes only the first two terms are important [2], [6]. Thus, $R(t)$ is approximated by

$$R(t) \approx R_0 + v_r(t-t_0), \tag{3}$$

where $v_r$ is the target velocity projected on the slant-range vector.

Assume that the radar transmits the $CW$ signal $e^{jw_0t}$. The received signal (usually termed azimuth signature) after quadrature demodulation is [7],

$$s(t) = q_T\, g(t) e^{\frac{j4\pi R(t)}{\lambda}}, \tag{4}$$

where $q_T$ represents the target complex reflectivity and $g(t)$ represents the two-way antenna azimuth pattern corrected for target velocity, i.e.,

$$g(t) = w_a\{(V-\dot{y}_0)(t-t_0)\}, \tag{5}$$

where $\dot{y}_0 = dy/dt$, for $t = t_0$. Equation (4) can now be written as

$$s(t) = q_T w_a[(V-\dot{y}_0)(t-t_0).]e^{j2kR_0}e^{j2kv_r(t-t_0)} \tag{6}$$

From equation (6) the effects of the target movement become evident: the factor $V-\dot{y}_0$ expands or contracts the azimuth signature depending on the target azimuth speed; the term $e^{j2kv_r(t-t_0)}$ corresponds to a Doppler shift of

$$\psi = \frac{2kv_r}{2\pi} \tag{7}$$

due to the object radial velocity.

### Range Migration

Besides Doppler-Shift and dilation effects in the azimuth signature, the target radial speed may be large enough to cause a walk through several range cells during the integration time.

For an object moving with cross-range velocity $v_a$, the integration time, $T$, is

$$T = \frac{\lambda R}{D(V-v_a)}. \tag{8}$$

If $\delta$ is the range cell resolution, the number of cells migration, $N_r$, is

$$N_r = \frac{\lambda R v_r}{D(V-v_a)\delta}. \tag{9}$$

The expected azimuth signature slope, after range compression, is expected to be

$$\Delta = \frac{N_r}{VT} = \frac{v_r}{V\delta}. \tag{10}$$

Thus, if the radial velocity is known, range migration poses no problem: the correction slope to perform on the full resolution range compressed data is $\Delta$.

## PROPOSED APPROACH

Our approach aims at the detection and imaging of selected targets exhibiting a predefined radial velocity and direction. The prior knowledge of these parameters allows to tune the azimuth compression filter to these targets. Range migration is therefore easily dealt

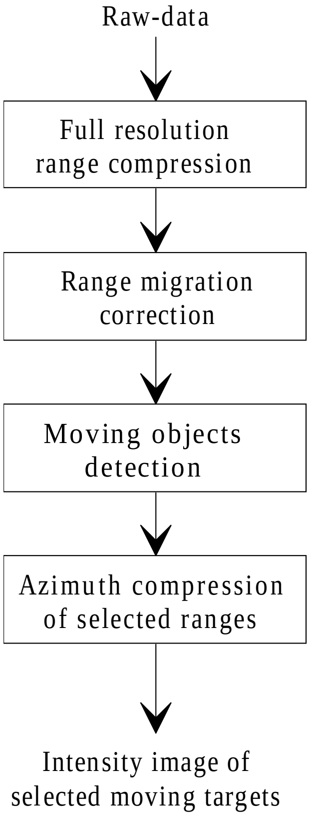

Figure 2: Block diagram of the imaging system

with. To detect a moving target within a certain radial speed, we implement a MTI based on the expected Doppler shift. The (static) ground and other moving targets that do not move according to the predefined parameters are filtered out in the frequency domain before azimuth compression. To reduce drastically the computational power required to compute the image, azimuth compression is done only for those ranges in which there is a positive MTI.

The proposed processing scheme is sketched in Fig. 2. The blocks after range compression have the following functions:

- Range Migration

  The range migration through adjacent resolution cells causes a reduction of the signal-to-clutter ratio (SCR), which can seriously impair the detection capabilities [1]. A common procedure to reduce the range migration effect is to use a low resolution channel in order to make range migration negligible. However, this procedure reduces the SCR.

  This is not the case in the present approach since we are only interested in targets with a predefined radial velocity.

  Supposing a platform velocity $V$, a radial velocity of interest $v_r$ and a range resolution $\delta$, the range migration through adjacent cells occurs with a slope that was shown in (10) to be

  $$\Delta = \frac{v_r}{V\delta}. \tag{11}$$

  Thus we implement the range correction after full resolution range compression, using the slope $\Delta$, making unnecessary the low-resolution channel.

- Moving Target Detection

  In conventional azimuth SAR processing the signals received from stationary targets on the ground are convolved with a reference function, which ideally is a replica of the signature of a stationary point target. The linear FM waveforms received from point stationary targets on the ground have a bandwidth of [6]

  $$B_D = 2V\theta_{3dB}/\lambda, \tag{12}$$

  where $\theta_{3dB}$ is the half-power antenna footprint.

  If there are moving objects in the illuminated scene, the azimuth signature will exhibit a Doppler shift of $2kv_r/2\pi$. In airborne SAR it is common to use a Pulse Repetition Frequency (PFR) greater than $B_D$ to improve the signal to noise ratio. This situation leads to regions in the frequency domain outside the interval $[-B_D/2, B_D/2]$ which contain returns from the moving targets. As shown previously if there are moving objects in the illuminated scene the azimuth signature will exhibit a Doppler shift of $\psi$. Assuming that the used PFR is greater than $B_D$, the signature will show a positive or negative shift, depending upon the moving target radial velocity. It is this fact that we use to image objects that not only have a selected $v_r$ but also are approaching or getting away from the platform.

  Defining $\gamma = \mathrm{sgn}(v_r)$, the signal of the desired radial velocity, for each range $X$ the following quantity is computed:

  $$MTI(X) = \int_{\gamma(|\psi|-B_D/2)}^{\gamma(|\psi|+B_D/2)} |S(f)|^2(1-\Pi(f/B_D/2)df, \tag{13}$$

  where $S(f)$ is the Fourier Transform of each range column. If $MTI(X)$ exceeds a predetermined

Table 1: Mission parameters used in simulation.

| Parameter | Value |
|---|---|
| Carrier frequency | 5GHz |
| Chirp bandwidth | 75MHz |
| Altitude | 10Km |
| Velocity | 300Km/h |
| Look angle | $20^0$ |
| Oversampling factor | 8 |

threshold, range $X$ is flagged as having targets moving at the selected velocity. The threshold is tuned according to the false alarm/detection probability requirements.

- Azimuth Compression

  One possible approach to moving target imaging is to use a shifted reference function in azimuth compression, with a frequency shift corresponding to a desired band. The alternative approach is to pre-filter the data prior to azimuth compression using a band-pass filter centered on one of the desired frequency bands, followed by a subsampling so that the remaining signals are aliased onto zero Doppler, as proposed in [2]. We follow the first approach, that is, a frequency shifted version of the reference function in azimuth compression, in the frequency domain. Those ranges which have a negative MTI are simply substituted by a zero column. The others are inverted by first filtering in the frequency domain the region of interest, thus zeroing the contribution from the static ground and contributions from other moving targets.

## SIMULATION RESULTS

In this section we present simulation results using the described techniques to detect and image moving objects with predefined moving parameters. Table 1 shows the simulation parameters. The simulation presented uses a PFR 8 times greater than the Doppler bandwidth of a static target. Such a PFR enables the simulation of objects with radial velocity high enough to produce non-negligible range walk. The simulation includes two targets with the same velocity (modulus), but traveling in opposite directions. Fig. 3 shows the raw-data after full resolution range compression. Range walk in opposite direction is visible: the target on the left move away from the platform, while the other is approaching (the platform travels from bottom to the top of the image). The modulo of the radial velocity is $|v_r| = 4.5\text{ms}^{-1}$.

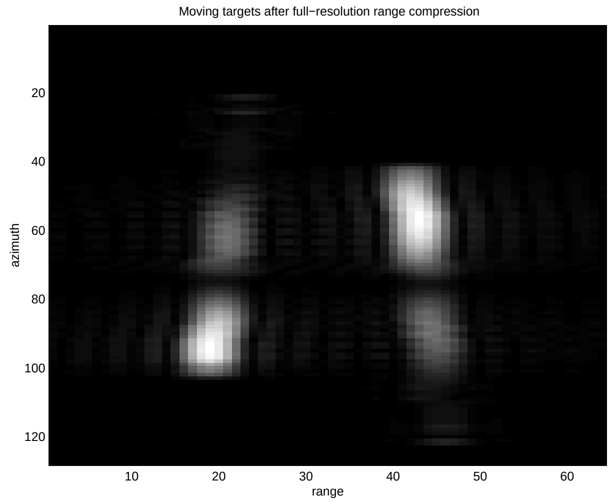

Figure 3: Full resolution range compressed image.

Fig. 4 shows the output of the range migration correction module: the azimuth signature of the left target becomes more degraded while the target of interest exhibits a vertical signature.

The MTI indicator for targets approaching the platform is plotted in Fig. 5; a peak is clearly distinguishable in the range position of 40m, corresponding to the target that moves towards the platform. The resulting image, after azimuth compression of the selected ranges, is shown in Fig. 6.

## CONCLUDING REMARKS

This work presented a processing scheme for efficient detection and ground-mapping of targets selected according to a user predetermined radial velocity and direction.

Range migration poses no problem because target velocity and direction is a-priori known. This knowledge makes unnecessary the use of a low-resolution channel for target detection. Instead, the full resolution range-compressed data is used, improving the signal to clutter ratio.

Moving target detection is computed based on the expected Doppler shift and traveling direction using a lower frequency band than usual methods, improving the SNR.

The computational power needed to compute the intensity image is drastically reduced, when compared with traditional methods, because range compression

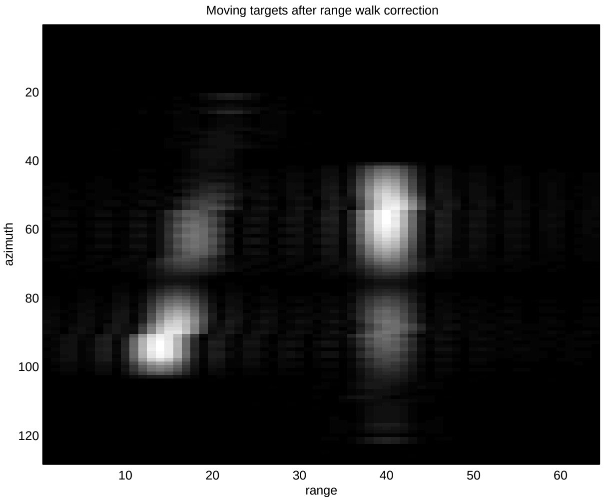

Figure 4: Output intensity image from the range correction module. The azimuth signature of the incoming target does not show range walk.

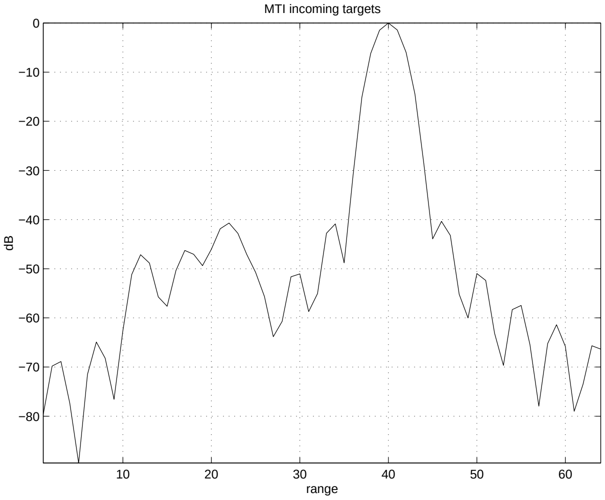

Figure 5: Moving target indication for approaching targets. The peak is correctly centered on range 40m

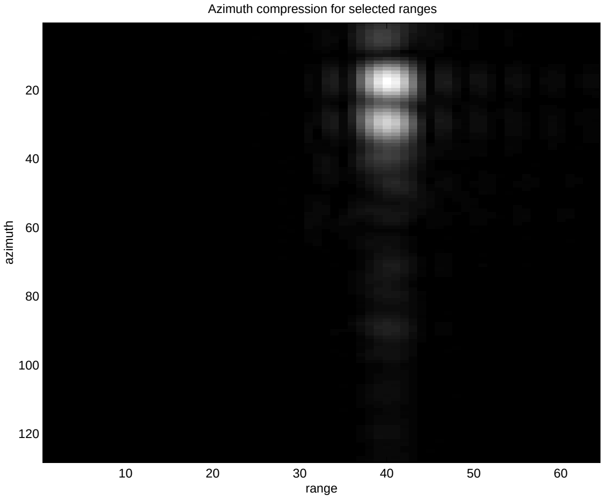

Figure 6: Resulting image of the approaching target.

is done only for those ranges where there is a positive moving target indication.

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