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SHORT COMMUNICATION

Chirp scaling Algorithm for modern Radar Processing

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Abstract- The chirp scaling algorithm (CSA) is based on the chirp scaling pulse compressed data. To remove the range variant nature of the system impulse response, the CSA operates by chirp scaling the linear frequency modulated (LFM) signal that already exists in the range-Doppler domain of the pulse compressed data. This LFM signal is commonly compensated for in the CS algorithm and the range-Doppler algorithm by secondary range compression (SRC). Chirp scaling of the uncompensated SRC signal allows the ACS algorithm to operate on pulse compressed data, removing the overhead associated with the processing of data that still contains the LFM transmitted pulse (as is necessary in the CS algorithm). In cases where chirp scaling of the uncompensated SRC chirp does not yield adequate results, a range chirp with a chirp length on the order of the maximum differential range migration across the scene can be inserted into the data, and this new chirp can be scaled during processing

I. INTRODUCTION

RADAR (radio detection and ranging) is a method of detecting distant objects and determining their position, speed, material composition, or other characteristics by causing radio waves to be reflected from them and analyzing the reflected waves. Synthetic Aperture Radar (SAR) is a kind of side looking radar (SLR) which is used for high resolution aerial and space based imaging of terrain, as shown in Figure.1. It can be used for all-weather and all-time. The term all-weather means that an image can be acquired in any weather conditions like clouds, fog or precipitation etc. and the term all-time means that an image can be acquired during day as well as night. With SAR it is possible to obtain detailed information quickly that may be of great use in combating such natural disasters like wildfires, oil-spills, ice and seas etc. SAR takes advantage of the forward motion of the platform while transmitting and receiving short waveforms or pulses to form the equivalent of a long antenna. It is a coherent system, in that it retains both the phase and magnitude of the received echoes which are synthesized in the signal processor to produce high resolution imagery. As a target (like a ship) first enters the radar beam, the backscattered echoes from each transmitted pulse begin to be recorded. As the platform continues to move forward, all echoes from the target for each pulse are recorded during the entire time that the target is within the beam. The point at which the target leaves the view of the radar beam some time later, determines the length of the simulated or synthesized antenna. The synthesized expanding beam-width, combined with the increased time, a target is within the beam and as ground range increases, it balances each other such that the resolution remains constant across the entire swath. The ideal flight path in stripmap SAR is a straight line at a constant altitude with no roll, pitch, or yaw. Ideally the sensor transmits pulses at equally spaced intervals (this implies a constant velocity for a fixed PRI). Also, the pointing direction of the antenna is such that the peak of the main lobe of the antenna is perpendicular to the flight track and has a constant grazing angle as shown in Figure.2.

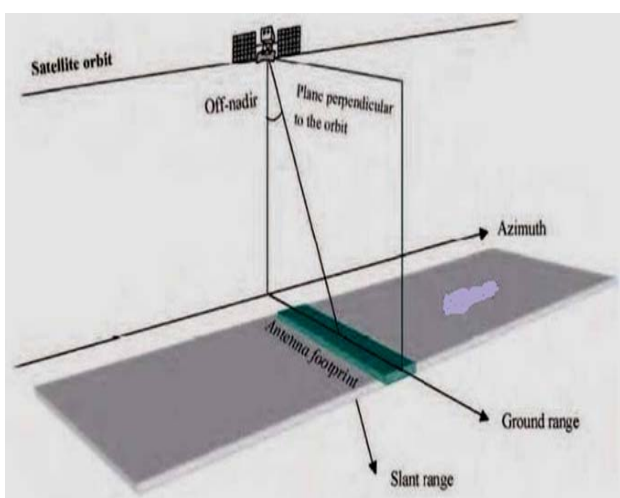

Figure.1 Conceptual view of stripmap SAR

For an ideal strip-map flight described by the vector (vt, 0, h) and a single point target at u0 = (0, y0, 0), for the relative range (R(t)), relative velocity (V_r), relative acceleration(a, Doppler frequency, and Doppler rate are as follows

$V_r(t)=$

$R(t)=$

$A_r(t)=$

$F_{Dop}(t)= -$

$F_{dop}(t)= -$

Where the red lines represent the antenna first-null beam-width for the two extreme pulsing locations where the reflector first enters the main lobe of the beam and finally leaves the main lobe of the beam, the blue line represents the closest range from the antenna to the reflector when the vehicle is passing by

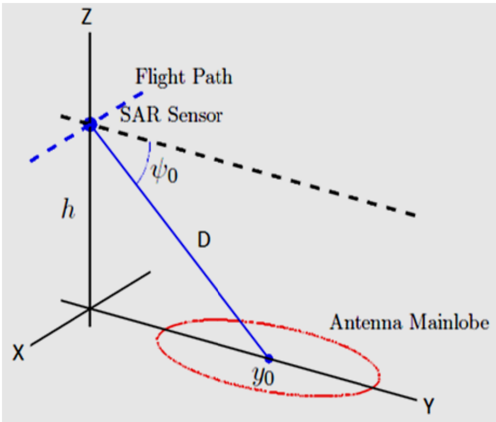

Figure.2 Data Model for stripmap Geometry

Length of the synthetic aperture as shown in Figure.3 is

$L_a =$ –

= 2*D* /(L* cos(A/2))

If Y << L (i.e. a narrow beam in azimuth), then cos(Vn/2) _ 1,giving

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The time the reflector is in the antenna beam is:

$T_a = L_a/v$

= 2*D* / (v*L* cos(A/2))

Cross-range resolution corresponding to the maximum synthetic aperture size is given by

a larger potential aperture gives a finer resolution. Increase in effective aperture size exactly cancels increase in beam-width with range. The difference between the maximum and the minimum Doppler shift across area of the beam-width is known as Doppler bandwidth. The upper and lower bounds on the PRF of a side-looking stripmap SAR are given by the relation:

$$2v / D_{az} <= PRF <= cD_{el}\tan\delta / 2\lambda R$$

The Nyquist sampling interval for side-looking stripmap SAR is

$$T_s = D_{az} / 2v \text{ sec}$$

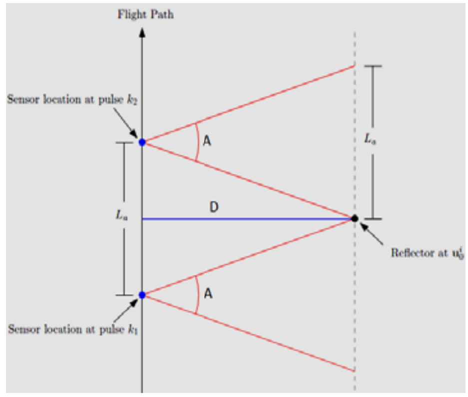

Figure.3 Stripmap Aperture Length

II. PROCESSING ALGORITHM

Several algorithms exist to process SAR data. There are three main classes of algorithms: frequency domain methods, time-domain methods, and “inverse problems” methods. There are many different frequency-domain algorithms for forming stripmap SAR images, such as the range-doppler algorithm (RDA), the w-k algorithm and the chirp scaling algorithm. The frequency-domain algorithms have low computational complexity because they utilize the efficient FFT algorithms. The frequency domain algorithms primarily differ in how the RCMC is accomplished. Some of the approximations, such as having a narrow beam in azimuth or the range to the scene, will determine which frequency domain algorithm will be better suited for a data set. A couple assumptions and limitations of the frequency-domain algorithms are that the vehicle is traveling at a constant velocity and pulses are transmitted at equally spaced intervals (this justifies the use of the FFT) and that the vehicle follows a perfectly straight flight path so that no uncompensated motion is present. A drawback to the frequency domain methods is that all the processing is done globally. This makes motion error along the flight path difficult to account for and hence the focusing in some areas might not be as good as in others. The frequency-domain algorithms do not explicitly account for noise in the system. There are also many different time-domain algorithms for forming strip-map SAR images, such as the range-stacking algorithm, time-domain correlation algorithm, convolution back-projection (CBP). The advantages of using a time-domain algorithm is that such things as unequally spaced pulsing intervals and compensating for motion is easily handled. The final class of imaging algorithm is “inverse-problems” methods. These approaches are model-based, that is they model the data acquisition of the SAR sensor, then they invert the model to recover the ground reflectivity.

III. CHIRP SCALING

The chirp scaling algorithm (CSA), also known as the differential range deramp algorithm has received widespread acceptance due to its efficient implementation and the ability to perform secondary range compression (SRC), which can limit the focusing accuracy of higher squint and wide-aperture systems using the RDA. This improvement is a benefit of the phase-history data being available in the 2-D frequency domain where SRC canbe made azimuth frequency dependent. While the RDA algorithm uses interpolation to implement range cell migration correction (RCMC), the CSA uses (a) frequency shifting to correct for the constant migration component, and (b) chirp scaling to correct for the linear migration component. As the scaling operation is better matched to chirp-encoded signals, a requirement for the CSA is that the signal or phase-history data must be chirped in the range direction. If the collection system employs de-ramp or de-chirp on receiving, as many do, the chirp encoding will need to be reapplied prior to the scaling operation. We consider a signal, such as a linear frequency-modulated (LFM) chirp, that is given by:

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with frequency-modulation (FM) rate Kr Hz, that is transmitted by a SAR. The signal is reflected off a point reference target and is migrated at different azimuth locations η due to constant changes in range throughout the synthetic aperture. The time taken for the signal to travel to the target and return is given by t = 2R/c, where R is the range of the target from the radar and c = 3*10^8 m/s is the speed of wave propagation in light. This scenario is depicted in Figure 2.1. The received baseband signal after the range migration is given by

$$s_r(t,\eta) = A_0 w_r\left(t - \frac{2R_\eta}{C}\right)$$
$$w_a(\eta - \frac{\eta_c}{C}) e^{-\frac{j4\pi f_0 R_\eta}{c_s\left(t-\frac{2R_\eta}{C}\right)}},$$
$$R_\eta = (R_0^2 + V_r^2\eta^2)^{1/2}$$

η is the azimuth time, A0 is an arbitrary complex constant, ηc is the beam center offset time, wr(t) is the rectangular range envelope function, wa(η) is the sinc-squared azimuth envelope function, f0 is the radar center frequency, Rη is the slant range at azimuth time η, R0 is the slant range of closest approach, and Vr is the effective radar velocity. To correct for this range migration and shift the signal to its proper location, a frequency modulation is applied to a chirp-encoded signal to achieve a shift or scaling of the signal. Note that the maximum shift or scale change that can be implemented by the frequency modulation cannot be too large in order to avoid any problems with the associated change in the signal's center frequency and bandwidth. This restriction is mitigated by applying RCMC in two steps so that only the difference in range cell migration (RCM) at different ranges is corrected in the chirp scaling operation and the bulk RCM is completed in the 2-D frequency domain along with SRC. Since the energy of a target should align along a constant range, the range to a target in this pulse will be the range for which the target energy of all pulses are corrected to. In other words, no RCMC will be applied to the pulse corresponding to ηo. We can also extended chirp scaling algorithm and also its analysis [1],[4]. The non-linear way of computation do exist[2]. The fractional chirp scaling algorithm (FrCSA) is based on the use of the fractional Fourier transform (FrFT) within the chirp scaling algorithm (CSA)[3]. Given phase-history data which is in the range-time/azimuth-time domain, the CSA steps are as follows.

1. The azimuth FFT is first computed in order to transform the received data, sr(t;h), into the range Doppler domain.
2. Chirp scaling is applied, using a phase multiply to equalize the range migration of all targets.
3. A range FFT is used to transform the data to the 2-D frequency domain.
4. A phase multiply is performed with a reference function, which applies range compression, SRC, and bulk RCMC in the same operation.
5. A range inverse FFT (IFFT) is performed to transform the data back to the range Doppler domain.
6. A phase multiply is performed to apply azimuth compression with a time varying match filter. A phase correction is also required as a result of the chirp scaling in step 2, which can be incorporated into the same phase multiply.
7. The final azimuth IFFT is computed to transform the compressed data to the SAR image domain.

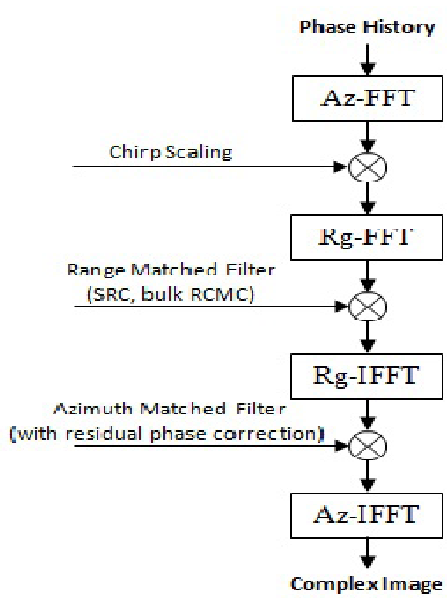

Figure.4 Processing Algorithm Steps

The received signal from the target consists of several parameters, which depicts azimuth chirp and range migration effect. The received signal consists of (i) amplitude range dependence and the elevation antenna pattern, (ii) part which reflects 2-way antenna pattern of the sensor, which represents the synthetic aperture length and is proportional to range r0, (iii) echo signal envelope and its position in fast time, (iv) the factor, which translates the range trajectory of the point scattered into a phase history, it is called azimuth chirp and its frequency is given by

$$f_D = \frac{1}{2\pi}\frac{d}{dt}\varphi(t - t_0) = \frac{-2}{\lambda}\frac{v^2}{r_0}(t - t_0)$$

It is also called Doppler frequency.

$$f_{DC} = f_D(t + t_c) = \frac{-2}{\lambda}\frac{v^2}{r_0}t_c = FM.t_c$$

The azimuth resolution is given by

$$A = 0.866v\cos\theta/f_{DC} \approx \frac{L}{2}$$

The azimuth resolution is independent of range, velocity or wavelength. The actual resolution is a function of how much of the bandwidth is processed and the combined shape of the beam pattern and the weighting function. The received and demodulated radar signal is referred to as the SAR signal space as it is still in its raw form and the two-dimensional image of the magnitude of the two-dimensional imaginary signal would not allow recognition of targets.

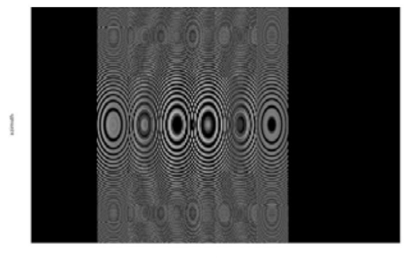

Figure.5 Echo returns of azimuthal chirp

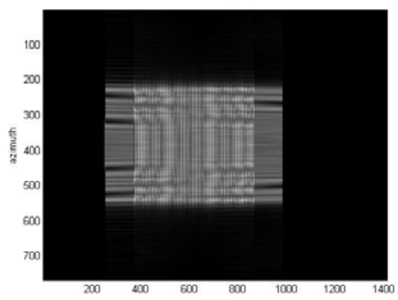

Figure.6 FFT of echo return of azimuthal chirp

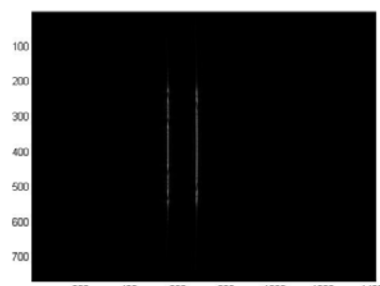

Figure.7 Range IFFT

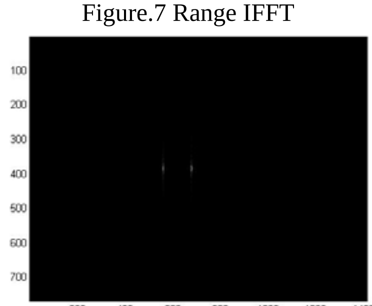

Figure.8 Azimuth FFT

REFERENCES

1.“An Extended Nonlinear Chirp-Scaling Algorithm for Focusing Large-Baseline Azimuth-Invariant Bi-static SAR Data” Hua Zhong and Xingzhao Liu, IEEE Geoscience And Remote Sensing Letters, vol. 6, no. 3, July 2009

2.. “Focusing Bistatic SAR Data Using the Nonlinear Chirp Scaling Algorithm", Frank H. Wong, Ian G. Cumming and Yew Lam Neo, IEEE Transactions On Geoscience and Remote Sensing, vol. 46, no. 9, September 2008

3. "Azimuth Fractional Transformation of the Fractional Chirp Scaling Algorithm (FrCSA)" Ahmed S. Amein, and John J. Soraghan, IEEE Transactions On Geoscience And Remote Sensing, vol. 44, no. 10, October 2006.

4. "Focusing of Medium-Earth-Orbit SAR With Advanced Nonlinear Chirp Scaling Algorithm", Lijia Huang, Xiaolan Qiu, Donghui Hu, and Chibiao Ding at IEEE Transactions On Geoscience And Remote Sensing, vol. 49, no. 1, January 2011

5. "Focus Improvement of High-Squint SAR Based on Azimuth Dependence of Quadratic Range Cell Migration Correction", Shuang-Xi Zhang, Meng-Dao Xing, Xiang-Gen Xia, Lei Zhang, Rui Guo, and Zheng Bao, IEEE Geoscience and Remote Sensing Letters, vol. 10, no. 1, January 2013