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OPTIMIZATION OF PHASE RESPONSE OF FOCUS FILTER IN SAR IMAGING

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Abstract: *Moving target is imaged in SAR imaging. The image of moving target is blurred due to the phase errors. The phase errors are reduced by minimizing the entropy of the image. The entropy of image of the moving target is estimated by using adaptive-order polynomial model. The sharpness improvement of image is achieved by optimization of phase response of azimuth filter through estimating the entropy. The performance of this method is better compared with the phase gradient algorithm.*

***Keywords**: phase errors, entropy, adaptive –order polynomial model, phase gradient algorithm.*

I. Introduction

SAR is a high–resolution airborne and space born remote sensing technique for imaging remote targets on a terrain or more generally on a scene. The modes of SAR operation can be divided into three according to the radar antenna's operation[7]. When the radar collects the electromagnetic (EC) reflectivity of the region alongside which it travels, observing a strip of a terrain parallel to the flight path, this mode is called side-looking SAR or strip map SAR. When the radar tracks and focuses its illumination to a fixed, particular area of interest, this mode is named spotlight SAR. Another mode of SAR operation is called scan SAR, which is especially used when the radar is flying at high altitude and to obtain a swath wider than the ambiguous range[5]. Strip map SAR antenna transmits a stream of radar pulses and collects the reflected back signal corresponding to each pulse. The rate or pulse repetition frequency (PRF) at which pulses are transmitted and received may be constant or may vary over time, since the moving antenna beam covers a strip of the earth's surface.

SAR imagery is based on successive signal processing algorithms called range compression and azimuth compression[4]-[5]. The usual raw data are in the form of a 2D multifrequency, multispatial scattered data. The range compression and azimuth compression are usually applied independently to obtain the ultimate SAR image.

II. Target Image Formation

SAR imaging can be carried out by the range Doppler algorithm[1], the chirp scaling algorithm[2], and the wave number-domain algorithm[3]. The range Doppler algorithm is used in our processing.

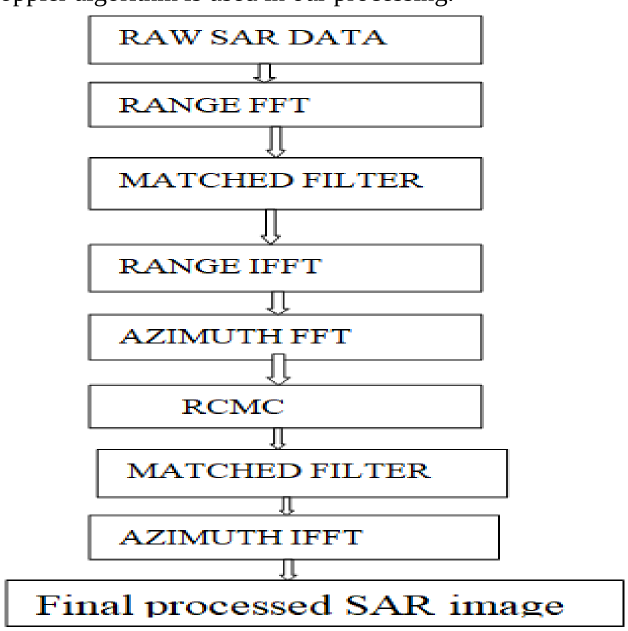

Fig 1: Range Doppler algorithm processing

In this algorithm , the received echo signals with different ranges from scatters are matched filter with the range reference signal, the echoes with different time delays in fast time are resolved and improves the range resolution. This process is referred as range compression. After range compression, the echo signals with different azimuths are matched filter with the azimuth reference signal, the echo signals with different positions in slow time are resolved. This process is known as azimuth compression. To obtain right-located, good focused image of target, clutter-lock, range migration correction applied to the range compressed signal before focus filtering. Usually the phase response of focus filter design is based on the radar moves regularly and target is at stationary. If the radar moves irregular or the target moves, the focus filter may not focus the signal well and the image may be blurred. In such cases the focus filter design is according to the received echo signals. This process referred to as autofocus.

Typical methods for autofocus include the sub-aperture-correlation method[1], the phase –gradient method[9], and the image–optimization method[2]. We consider the image-optimization method for well focusing the image of the target. In this image-optimization autofocus, the phase response of the focus filter is designed to optimize the focus quality of the image. The focus quality of the image can be measured by the entropy[2]. The phase response of the focus filter is modeled as a specially designed polynomial , and the coefficients of this polynomial are adjusted in sequence to minimize the entropy of the image. The order of this polynomial is adaptive, and thus this algorithm applies more widely than the phase gradient method.

III. Implementation

The echo signal from target is represented as

$$X(t)= w \exp\left(-j \frac{4\pi R}{\lambda}\right) \qquad (1)$$

Where m is slow time ,w is the scattering coefficient, R is the range of the target to the radar, and λ is the carrier wavelength.

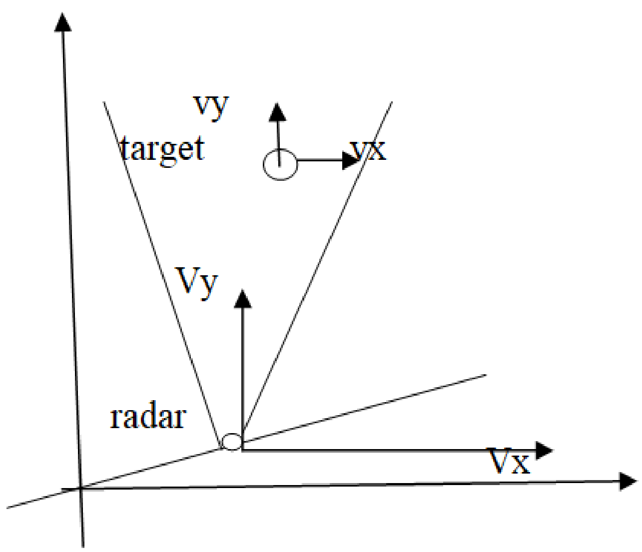

Fig. 2. Geometrical representation of SAR imaging

Here R is Written as

$$R=\sqrt{(y0 + vyt - Vyt)^2 + (x0 + vxt - Vxt)^2} \qquad (2)$$

Geometry of SAR imaging is as shown in fig(2),R is derived from the imaging plane. The y-axis directed along the radar boresight. The radar moves with velocity Vx in the x-axis and velocity Vy in the y-axis. Let us assume that at t=0 the radar is situated at (0,0). The target moves with velocity vx in the x-axis and velocity vy in the y-axis and it is situated at (x0,y0) at t=0.

Let after some time t=ts the radar boresight is directed to the target, therefore

$$ts = \frac{x0}{Vx - vx} \qquad (3)$$

and rs be the range of the scatter to the radar at ts is given by

$$rs = y0 + vy\,ts - Vy\,ts \qquad (4)$$

approximating R by its second-order Taylors series at ts,

$$R = rs - (Vy - vy)(t - ts) + \frac{(Vx-vx)^2}{2\,rs}\,(t-ts)^2 \qquad (5)$$

Then substitute (5) into (1) yields

$$X(t) = w \exp\left\{-j\frac{4\pi}{\lambda}\left[rs - (Vy - vy)(t - ts) + \frac{(Vx-vx)^2(t-ts)^2}{2\,rs}\right]\right\} \qquad (6)$$

The Fourier transform of X(t) is approximately

$$X(\omega) = w\sqrt{\frac{\lambda\,rs}{2(Vx-vx)^2}}\,\exp\left[-j\frac{\pi}{4} - j\frac{4\pi}{\lambda}rs - j\,\omega ts + j\,\frac{\lambda\,rs}{8\pi(Vx-vx)^2}\,(\omega-\omega c)^2\right] \qquad (7)$$

The instantaneous Doppler rate ω in radians and ωc be the Doppler centroid in radians.
Therefore the phase response of focus filter should be

$$\emptyset(\omega) = -\frac{\lambda\,rs}{8\pi(Vx-vx)^2}\,(\omega-\omega c)^2. \qquad (8)$$

Extending (8) to the fundamental interval and discretizing ω, we obtain

$$\Phi(k) = \begin{cases} -\pi\beta\left(\frac{k-k0}{M}\right)^2 & 0 \le k \le k0 + \frac{M}{2} \\ -\pi\beta\left(\frac{k-k0-M}{M}\right)^2 & k0 + \frac{M}{2} \le k \le M \end{cases} \qquad (9)$$

Where k0 is the Doppler centriod in the interval of ω i.e

$$k0 = \frac{M}{2\pi}\,\omega 0$$

Where $\beta = \frac{\lambda\,rs}{2T^2\;(Vx-vx)^2}$ (10)

M is the number of Doppler samples and T is the pulse repetition period.

Autofocus

The phase errors are occurred due to different slant ranges of target points or different azimuths with same slant range of target points. Therefore different azimuth filters are to be required for different target points. Actually, for a small size object area only one azimuth filter is sufficient. Generally small size target patch consists of different target points with same phase errors.

The small size object area focusing is achieved by a focus filter, that is written as

$$P(m,n)=\frac{1}{M}\sum_{k=0}^{M-1} Q(k,n)\exp\left[(j\,\Phi(k)\right]\exp\left(j\frac{2\pi}{M}km\right) \quad (11)$$

Doppler rate, azimuth, and fast time are indexed by k, m and n, respectively. The focused small size object area is Q(k,n), and the phase response of azimuth filter is Φ(k). P(m,n) is the complex image. The focus quality of complex image P(m,n) is improved by reducing phase errors of focus filter. The phase response Φ(k) of azimuth filter is optimized until to minimize the entropy of $|P(m,n)|^2$.

The entropy of $|P(m,n)|^2$ is defined as

$$\mathcal{E}[|P(m,n)|^2]=\sum_{m=0}^{M-1}\sum_{n=0}^{N-1}\frac{|P(m,n)|^2}{S}\ln\frac{S}{|P(m,n)|^2} \quad (12)$$

Where $S = \sum_{m=0}^{M-1}\sum_{n=0}^{N-1}|P(m,n)|^2$ (13)

In SAR imaging, the entropy can be used to measure the smoothness of a distribution function, using this characteristic of entropy, sharpness of an image to be calculated.[9]-[14]. The entropy of $|P(m,n)|^2$ is minimized i.e phase errors of focus filter are reduced, and focus quality of complex image is improved.

Let the focus filter's amplitude response is ed to be a unit and S is a constant. Therefore the entropy of image can be determined by

$$\mathcal{E}[|P(m,n)|^2] = -\sum_{m=0}^{M-1}\sum_{n=0}^{N-1}|P(m,n)|^2\ln|P(m,n)|^2 \quad (14)$$

Thus ,the entropy of image to be minimize through estimating the phase response of the azimuth filer (14).

Estimation of Φ(k) using an Adaptive-order polynomial model

We model **Φ(k)** as a polynomial , i.e .,

$$\Phi(k) = \begin{cases} -\sum_{i=2}^{i=I}\frac{\pi\beta i}{i}\left(\frac{k-k0}{M}\right)^{i} & 0 \le k \le k0+\frac{M}{2} \\ -\sum_{i=2}^{i=I}\frac{\pi\beta i}{i}\left(\frac{k-k0-M}{M}\right)^{i} & k0+\frac{M}{2} \le k \le M \end{cases}$$

Estimation of Φ(k) is depending upon the parameter βi. To improve the computational efficiency, the signal is focused using conventional focus filter before autofocus.

First β2 is increased step by step until entropy Ɛ [.] is minimized. If Ɛ [.] can not be minimized β2 is varied in opposite direction until the entropy of image Ɛ[.] is minimized. this process is repeated for β3, β4 and so on until Ɛ [.] minimized. The phase response Φ(k) is adjustable, if further increase in order, the estimate of βi approaches to zero and therefore the higher order terms are ignorable basically, when the estimates of two successive βi are equal to zero.

Estimation of Φ(k) using an phase gradient autofocus algorithm as follows

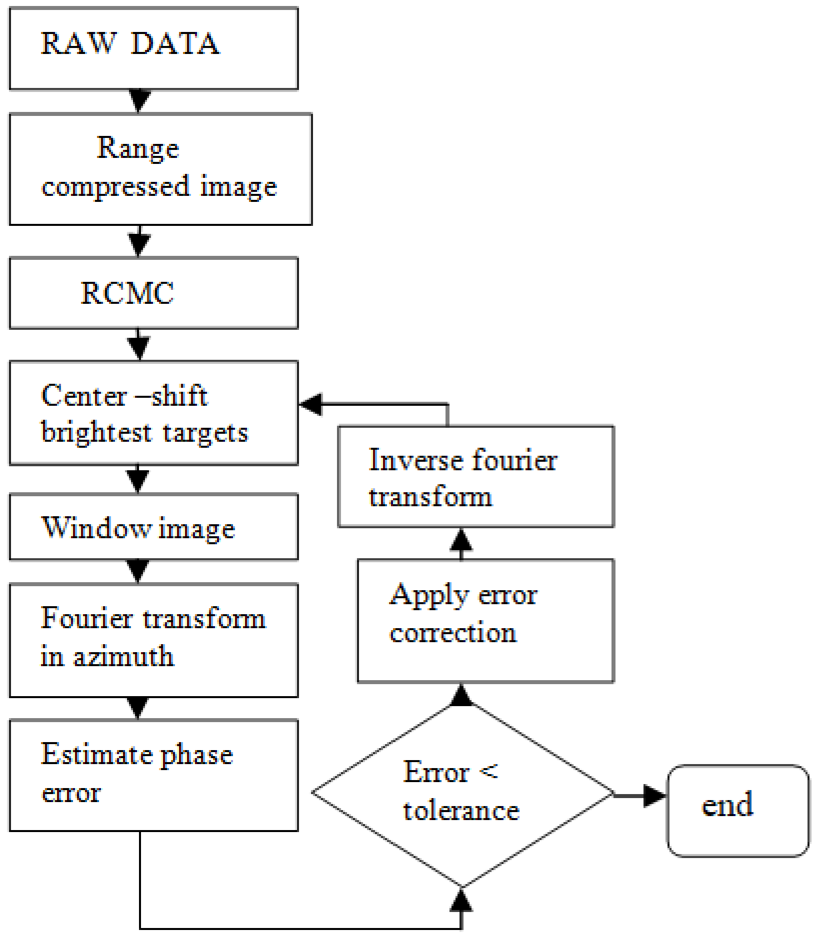

Fig.3. Phase gradient autofocus algorithm

The Phase errors are estimated and corrected by using PGA Algorithm [9] until the phase errors are minimized.

V. Results

A set of simulated data is used to test our technique .the radar is carried on a platform moving at a velocity of 100m/s. It transmits pulses at a period of 0.0063s.The beam is directed broadside and has an angle of 0 rad in azimuth. The pulses have a wavelength of 0.3m and a bandwidth of 150MHz and 1024 echoes with 512 range bins each are considered. When the slow time is zero, the platform is situated at (0,0) and the center of the target is situated at (0,3km). For stationary target the final focused image or azimuth compressed image using PGA, and Minimum entropy autofocus using an Adaptive-order polynomial model methods are shown in fig.4., and fig.5., respectively. If the target moves with 4m/s radial velocity and with 1m/s cross range velocity, then the final focused or azimuth compressed signal using PGA, and minimum entropy autofocus using an Adaptive-order polynomial model methods are as shown in fig.6., and fig.7., respectively.

We observed that well focused image with minimum entropy using an Adaptive-order polynomial model is obtained compared with PGA autofocus. For stationary as well as moving target, the performance of proposed adaptive-order polynomial model for minimizing the entropy of image is better compared with the PGA autofocus.

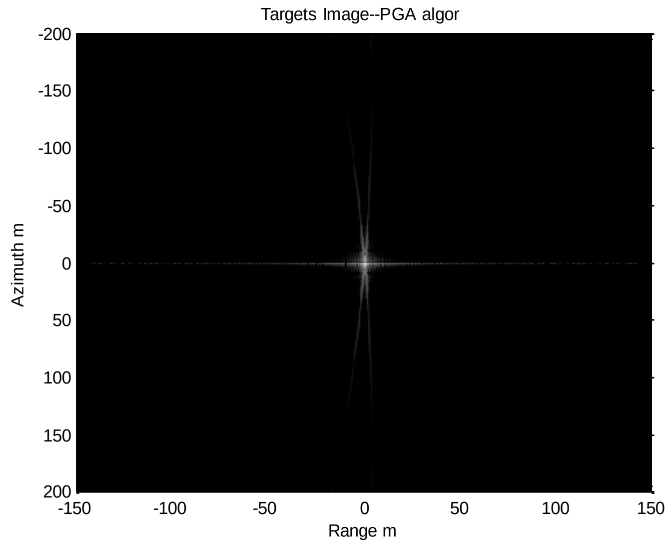

Fig.4. azimuth compressed signal using PGA for stationary target

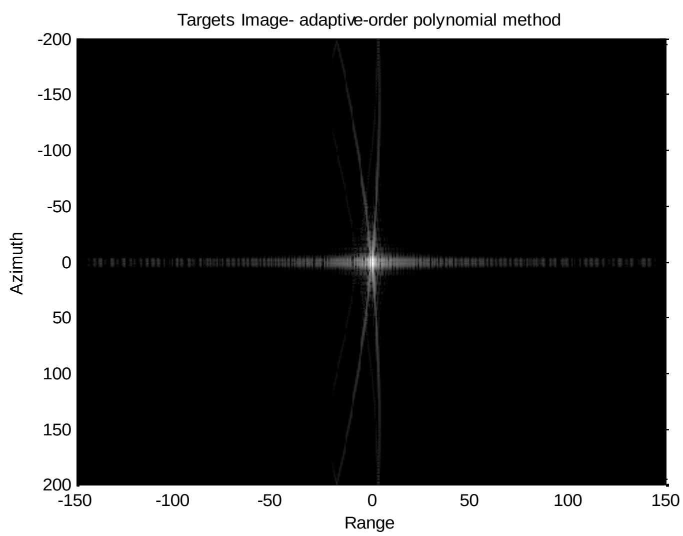

Fig.5. azimuth compressed signal using MEA with adaptive –order polynomial model for stationary target

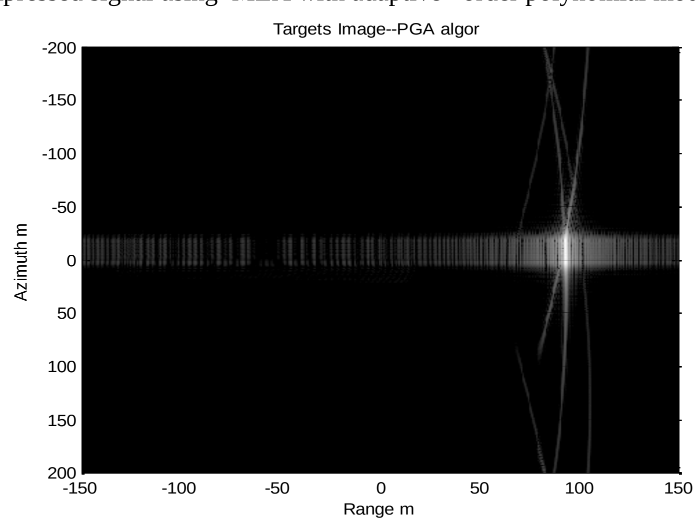

Fig.6.azimuth compressed signal using PGA for moving target

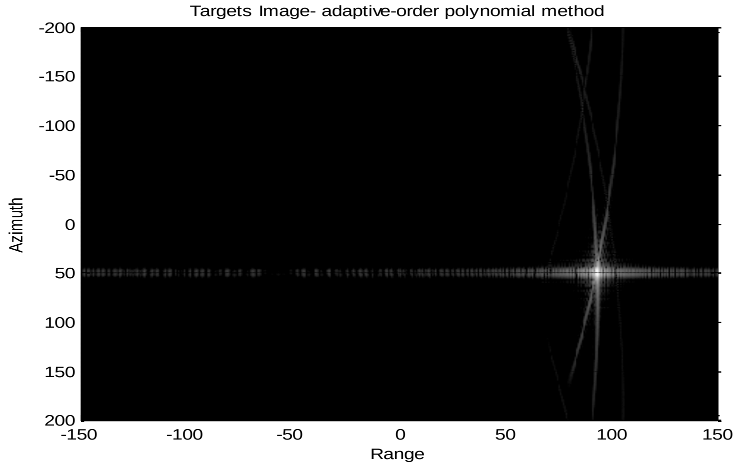

Fig.7. azimuth compressed signal using MEA With adaptive –order polynomial model for moving target

TABLE –1
comparison of entropies for stationary target using PGA and MEA using adaptive –order polynomial model

S.No	Doppler frequency rate(fr=1/β)	Entropy by PGA.	Entropy by proposed MEA.
1	-26.667	-	3.3323+e03
2	-33.1013	2.9745e+03	2.9719e+03
3	-33.2020	2.9782e+03	2.9736+e03
4	-33.2750	2.9819e+03	-
5	-33.3274	2.9850e+03	2.9798+e03
6	-33.3647	2.9873e+03	2.9889+e03
7	-33.3912	2.9884e+03	2.9836+e03
8	-33.4473	2.9890e+03	-
9	-33.4497	2.9891e+03	2.9709+e03
10	-33.8983	-	2.9620+e04

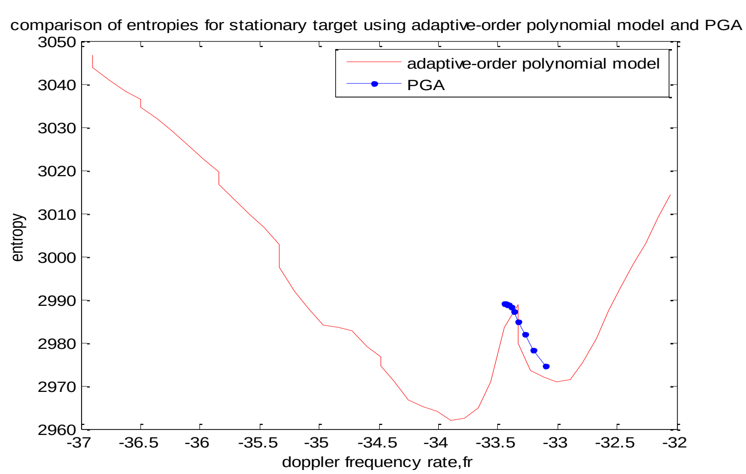

Fig.8. comparison of entropies for stationary target using PGA And MEA using adaptive –order polynomial model

Table-1 and fig.8. shows that entropy v/s Doppler frequency rate(fr=1/β). for stationary target the minimum entropy is 12.5 less than using adaptive-order polynomial model compared to PGA method. Therefore the phase errors reduced in stationary target by adaptive- order polynomial model more compared to PGA. Execution time for both cases are approximately equal i.e 5sec.

TABLE – 2

comparison of entropies for moving target using PGA and MEA using adaptive –order polynomial model

S.No	Doppler frequency rate(fr=1/β)	Entropy by PGA.	Entropy by proposed MEA.
1	-33.8419	3.0317e+03	3.0350e+03
2	-34.4998	3.0224e+03	3.0220e+03
3	-34.9999	3.0257e+03	3.0248e+03
4	-35.4007	3.0307e+03	3.0313e+03
5	-35.7137	3.0340e+03	3.0354e+03
6	-35.9618	3.0373e+03	3.0376e+03
7	-36.1547	3.0397e+03	3.0400e+03
8	-36.3095	3.0424e+03	3.0430e+03
9	-36.5318	3.0442e+03	3.0443e+03
10	-36.7328	3.0463e+03	3.0463e+03
11	-36.8453	3.0480e+03	3.0488e+03

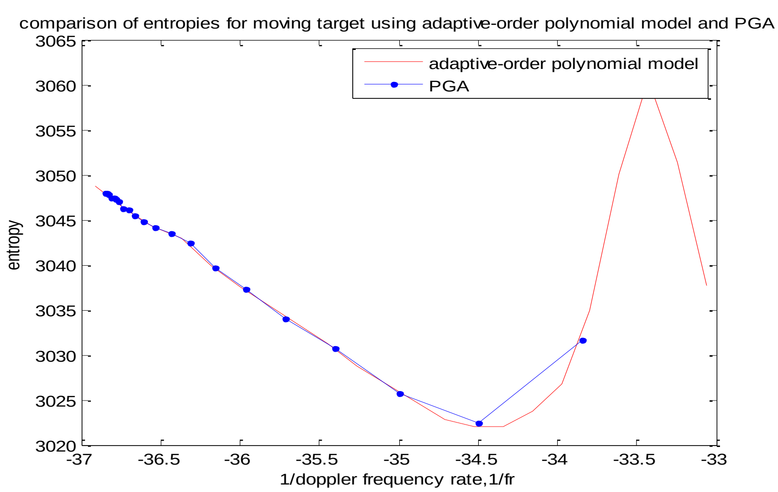

Fig.9. comparison of entropies for moving target using PGA and MEA using adaptive –order polynomial model

Table-2 and fig.9. shows that the minimized values of entropy v/s Doppler frequency rate(fr=1/β) of moving target with radial velocity 4m/s in both adaptive-order polynomial model and PGA are increased in comparison with stationary target, because of phase errors due to velocity of target. Entropy value using adaptive-order polynomial model is 0.4 less than the PGA method. Execution time for PGA method is approximately 10 minutes more than adaptive-order polynomial model.

TABLE –3
Comparison of minimum Entropies with different radial velocities of moving target

S.No	Radial velocity of target(m/s)	Minimum Entropy by PGA	Minimum Entropy by MEA
1	0	2.9745e+03	2.9620e+03
2	2	3.0065e+03	2.9908e+03
3	4	3.0224e+03	3.0220e+03
4	6	3.0790e+03	3.0795e+03
5	8	3.1524e+03	3.1359e+03
6	10	3.2390e+03	3.1504e+03

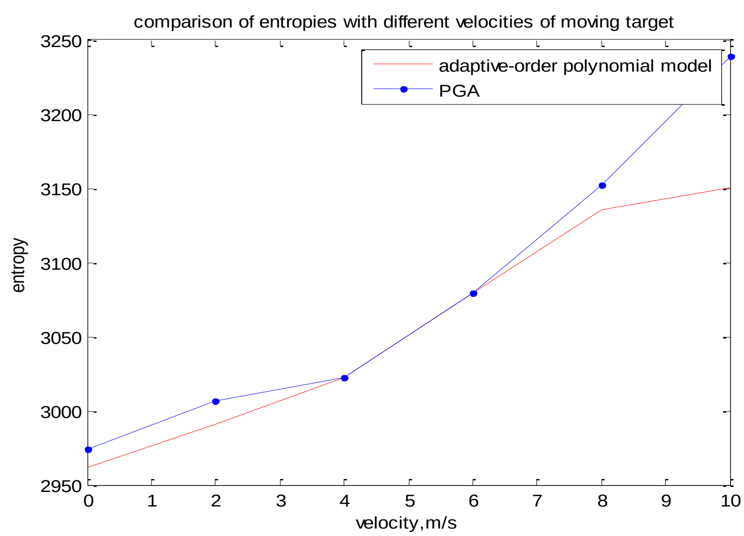

Fig.10. comparison of minimum entropies with different radial velocities.

Table-3 and fig.10 shows that entropy v/s radial velocity (m/s)of target, the radial velocity of target increases the phase errors of moving target. These errors are reduced by minimizing the entropy of target image. Average entropy value 22.06 of target image using adaptive-order polynomial model is less than compared to PGA method. The execution time for PGA method is increased, when the velocity of target is increased, in adaptive –order polynomial model execution time is not affected by velocity.

The real data is used for testing the PGA and proposed autofocus algorithm. The real x-band resourcesat-2 data was provided by Bhuvan, Indian Geo-platform of ISRO, as show in fig.11., for testing the algorithms, a known phase error was added to the real data, as shown in fig.12., then the PGA and adaptive-order polynomial model was applied to the artificially corrupted real image for reducing the phase errors. Fig.13., and fig.14., shows the recovered images using PGA and adaptive-order polynomial model method respectively.

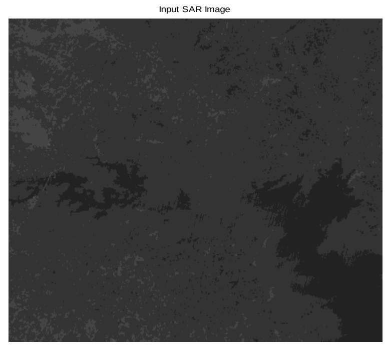

Fig.11.real X-band resourcesat-2 data

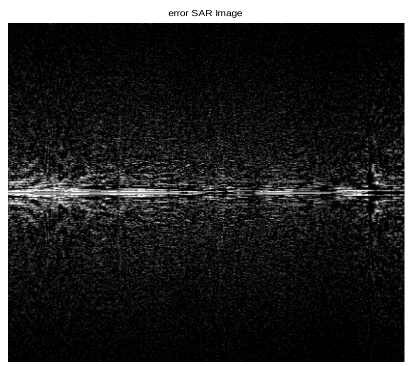

Fig.12. known phase error added to the real data

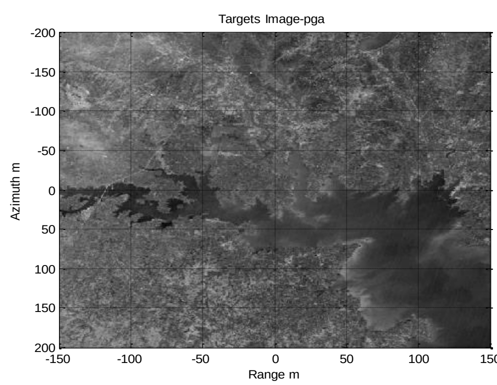

Fig.13. recovered image by PGA method

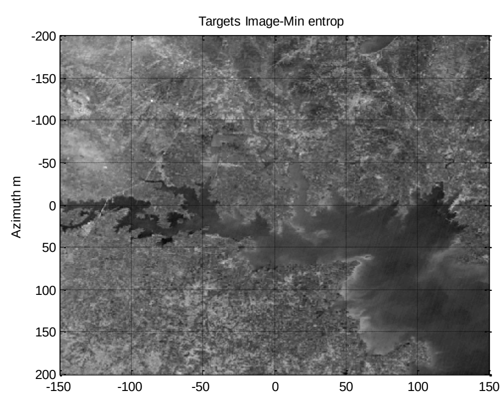

Fig.14. recovered image by adaptive-order polynomial model method

Table-4

S.No	Entropy by PGA.	Entropy by proposed MEA.
1	3.1919e+03	3.1852e+03

Table-4 shows the entropy values of focused data using proposed method is 6.7 less than PGA method. Therefore the adaptive-order polynomial model algorithm performance good compared to PGA method.

VI. Conclusion

The adaptive-order polynomial model optimization method of phase response of focus filter is effective for autofocus in SAR imaging. Azimuth filter Phase response is estimated by using adaptive-order polynomial model. The polynomial coefficients are adapted to reduce the phase errors of received signal, and thus the entropy of image is minimized , therefore well focused image is obtained for both stationary as well as moving targets compared with PGA method. The adaptive-order polynomial model method is less complex and execution time is less in comparison with PGA method.

References

[1] curlander,J.C., and McDonough, R.N. S*ynthetic Aperture Radar: systems and signal processing*. New York, NY: John Wiley & Sons, 1991.

[2] R.K.Raney, H.Runge, R.Bamler, G.Cumming,, and F.H.Wong '*Precision SAR Processing Using Chirp Scaling', IEEE Transactions on Geosci, remote Sens., vol.32, no.4,pp.786- 799,jul.1994*

[3] R.Bamler "Acomparison of range-doppler and wave number domain SAR focusing algorithms". *IEEE Transactions on Geosci, remote Sens., vol.30, no.4,pp.706- 713,jul.1992*

[4] Wang,J., and Liu,X., *SAR minimum- entropy autofocus using an adaptive - order polynomial model. IEEE Geoscience and Remote Sensing Letters,3* 4(oct,2006,512-516

[5] Wang,J., and Liu,X., Automatic correction of range migration in SAR imaging. *IEEE Geoscience and Remote Sensing Letters,7.2*(Apr,2010),256-260.

[6] Wang,J., and Liu,X., Velocity estimation of moving targets in SAR imaging. *IEEE Tranasaections on Aerospace and Electronic System, 50. 2*(Apr, 2014),1543-1548.

[7] caner ozdemir *inverse synthetic aperture radar imaging with matlab algorithms wiley series in microwave and optical engineering*.

[8] Y.K.Chan and V.C.Koo *An introduction to synthetic aperture radar(SAR)* .

[9] D.E.WAHL, P.H.EICHEL, D.C. GHIGLIA and C.V JAKOWATZ Phase Gradiant Autofocus – A Robust Tool for High Resolution SAR Phase Correction. *IEEE Tranasaections on Aerospace and Electronic System,30. 3*(july,1994),827-835.

[10] BHUVAN, Indian Geo-platform of ISRO

