Design of a new algorithm MFCFT using ISAR imaging to improve the Cross-Range Resolution and Computation Time

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Abstract

***ISAR* imaging is a 2D Radar imaging *that produces high resolution images of targets like Ships and Airplane. It uses RD, RID and RIC methods for smoothly rotating, highly rotating and maneuvering targets respectively to generate the images. In this paper, the imaging is done using a new algorithm MFCFT to improve the Cross range resolution and computation time and comparison with different algorithms is shown through the simulated results*.**

Keywords: MFCFT, RD, RID, RIC

1. Introduction

Inverse Synthetic Aperture Radar (ISAR) imaging is a HRR imaging of Naval targets like Ship, Airplane, Missiles etc., in 2D plane. The two dimensions are Down Range and Cross Range. The down range resolution is obtained by transmitting pulses having narrow pulse widths. The Cross Range Resolution(CRR) is obtained through ISAR technique by integrating all the echoes obtained at different aspects when the target is rotating. The conventional method is Range Doppler (RD) Method, which considers uniform rotation of the target [1], where basic FFT algorithm is used to produce the ISAR images. If the target rotates with non-uniform motion, RD method fails and Range Instantaneous Doppler (RID) method is used [2]. In this method, some time-frequency transforms like Short Time Frequency Transform(STFT), Gabor Transform(GT), and Weiner Ville distribution algorithms are used to generate images [3-5]. In case of complex maneuvering of the target, RID method fails and Range Instantaneous Chirp (RIC) method is used [6-7]. Here, Discrete Chirp Fourier Transform(DCFT), Modified DCFT and Modified Fast Chirp Fourier Transform(MFCFT) algorithms are used to produce the images [8-10]. In this paper, an improvement in CRR and computation time is shown with the new MFCFT algorithm by comparing with various algorithms like GT and DCFT. The DRR is kept as 1mt for all methods.

2.Mathematical Modelling

Consider the ISAR imaging model as shown in Figure 1.

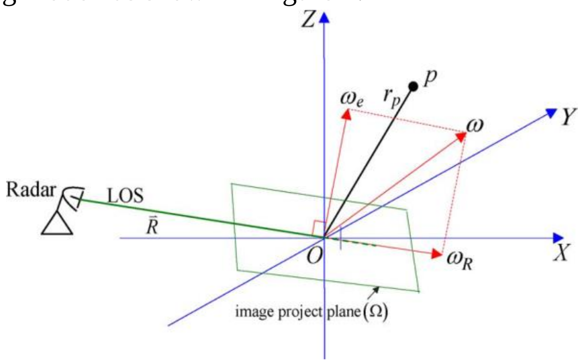

Figure 1. Imaging model

The above figure shows, O is the origin representing the rotating centre of target and ω is a vector representing the 3D angular velocity of moving target. ω can be decomposed into ω_R and ω_e in the plane determined by ω and RLoS whose unit vector is R. Here, ω_R and ω_e are the components parallel and perpendicular to R. ω_R does not cause radial motion and hence has no effect on phase of echo signal, whereas the radial motion caused by ω_e affects the phase and cause the change of the Doppler frequency, which is utilized to realize HR azimuth imaging. Hence, ω_e is called the effective rotating vector.

If transmitted signal is an LFM waveform represented by S(t) and is given by [1]

$$S(t) = rect\left(\frac{t}{T_p}\right)\exp\left[j2\pi\left(f_c t + \frac{1}{2}\gamma t^2\right)\right] \quad (1)$$

$$|t| \le \frac{T_p}{2}$$

where f_c is carrier frequency, γ is chirp rate. Assume there are P scattering points and the received echo signal from point scatter ‘p’ of equal magnitude is given by

$$S'(t) = \sum_{p=1}^{P}\exp\left[j2\pi\left(f_c\left(t - \frac{2R(t)}{c}\right) + \frac{1}{2}\gamma\left(t - \frac{2R(t)}{c}\right)^2\right)\right] \quad (2)$$

The ISAR signal for a 2D image is represented as [1]

$$S(x,t) = \sum_{p=1}^{P}\exp\left[j\frac{4\pi}{\lambda}(R_0 + x_p(\omega t) + y_p)\right] \quad (3)$$

Equation (3) is the final expression to which FFT algorithm is applied to obtain final ISAR image. For imaging in 2D using RID method only two complex motions ω_{ex} and ω_{ey} are considered for a scattering point ‘p’ located at (x_p, y_p) on the target. The received echo signal for RID corresponding to each range cell is given by [2]

$$S(t_m) = \sum_{p=1}^{p} a_p \exp\left[j\left(\theta_p + f_p t_m + \frac{1}{2}\gamma_p (t_m)^2\right)\right] + e_p(t_m)$$

$$f_p = \frac{4\pi}{\lambda}\left(x_p\omega_y - y_p\omega_x\right) \quad (4)$$

$$\gamma_p = \frac{4\pi}{\lambda}\left(x_p\alpha_y - y_p\alpha_x\right)$$

where θ_p is constant phase term of P^{th} scatter respectively. Here, in case of RID Gabor transform is applied to equation (4) to obtain final ISAR image. In case of RIC method, if only P scatters are there in a range cell, the echo corresponding to this cell can be expressed as the cubic phase signal i.e., cubic chirp which is given by

$$S(t_m) = \sum_{p=1}^{p} a_p \exp\left[j\left(\theta_p + 2\pi\left(f_p t_m + \frac{1}{2}\gamma_p {t_m}^2 + \frac{1}{6}\beta_p t_m^3\right)\right)\right]$$

$$\theta_p = -\left(\frac{4\pi}{\lambda}\right)\Delta R_{pp}(t_0)$$

$$f_p = -\frac{2}{\lambda}\left(\omega . r^T\right) \quad (5)$$

$$\gamma_p = -\frac{2}{\lambda}\left(\alpha . r^T\right)$$

$$\beta_p = -\frac{2}{\lambda}\left(\zeta . r^T\right)$$

where a_p is the amplitude, θ_p - initial phase, f_p - center frequency, γ_p - chirp rate and β_p - derivative of chirp rate of azimuth echoes associated with P^{th} scatter. In this case, DCFT and MFCFT algorithms are applied to equation (5) to obtain the image.

3. Algorithms for ISAR Imaging

i. Gabor Transform(GT)

The GT of signal x(t) is defined by equation as given below

$$x(t) = \sum_{p=1}^{\infty} B_p(t).G_p(t) \quad (6)$$

where, $B_p(t)$ - radar echo signal in time domain, $G_p(t)$ - wavelet function of GT and is defined as[4]

$$G_p(t) = \frac{1}{\sqrt{2\pi\alpha^2}} \exp\left\{-\frac{(t-\tau_p)^2}{2\alpha}\right\} \exp\left(j2\pi w_p (t-\tau_p)\right) \quad (7)$$

here τ_p - shifting factor, w_p - Gaussian window modulation parameter and its value is set to be less than or equal to PRF and α is the blurring factor.

ii. Discrete Chirp Fourier Transform(DCFT)

DCFT for cubic chirps is represented as [8]

$$Y(k,l,m) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} x(n) W_N^{kn+\ln^2+mn^3} \quad (8)$$

$$0 \le k,l,m \le N-1$$

where k, l & m are integers representing constant frequency, chirp rate and rate of change of chirp rate respectively.

iii. New Algorithm-MFCFT

MFCFT is represented by [10]

$$Y(k,l,m) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} y(n) W_N^{kn+(l/N)n^2+(m/N)n^3} \quad (9)$$

$$0 \le k,l,m \le N-1$$

This method is found to be better than MDCFT, because the estimated parameters, k varies from 0,1…N-1, *l* and m varies from (0,1/N,..,N-1/N). Here, the accuracy of parameter estimation increases compared to DCFT and shorter near the peak value is obtained, so that the time taken for computation is significantly reduced.

4.Simulation Results

A. Ship target with 13 scattering points

Figure.2 shows the simulated ship target with 13 scattering points. Figures.3,4&5 represents the ISAR images using Gabor Transform, DCFT and MFCFT respectively. From these images clearly one can observe the improvement in CRR. It is shown in Table.1

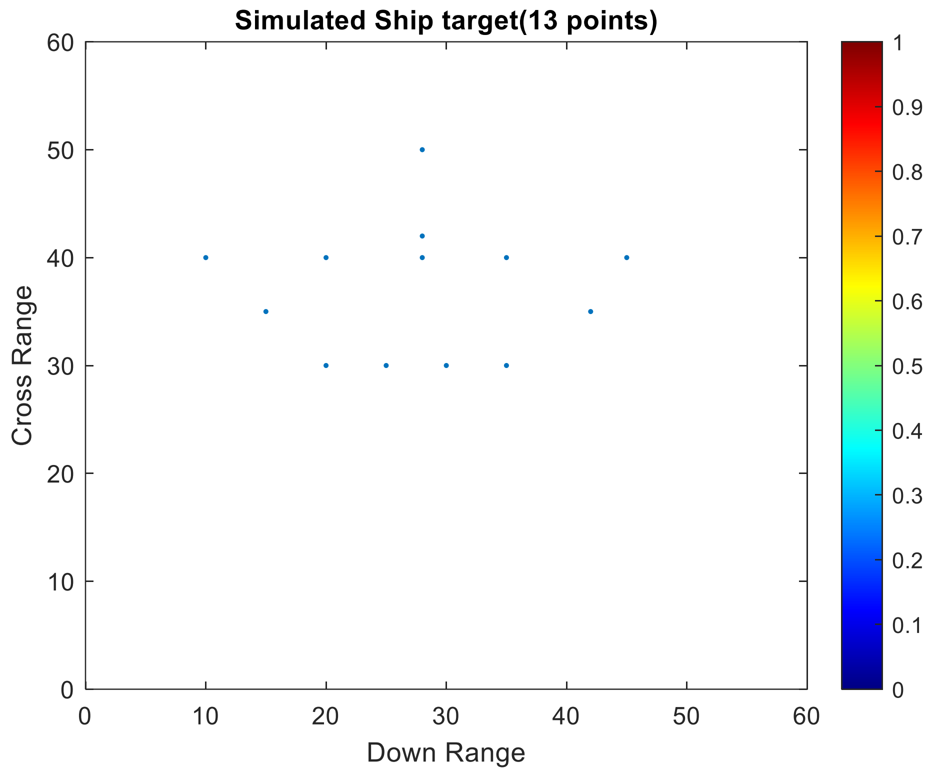

Figure 2. Simulated ship target with 13 points

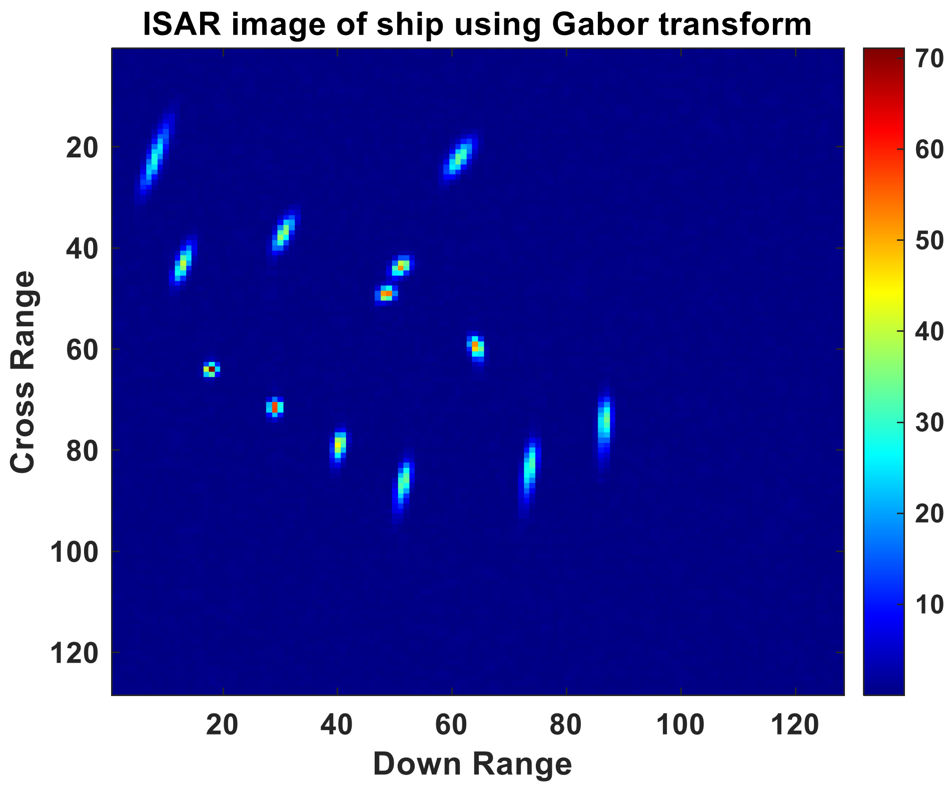

Figure 3. ISAR image using GT

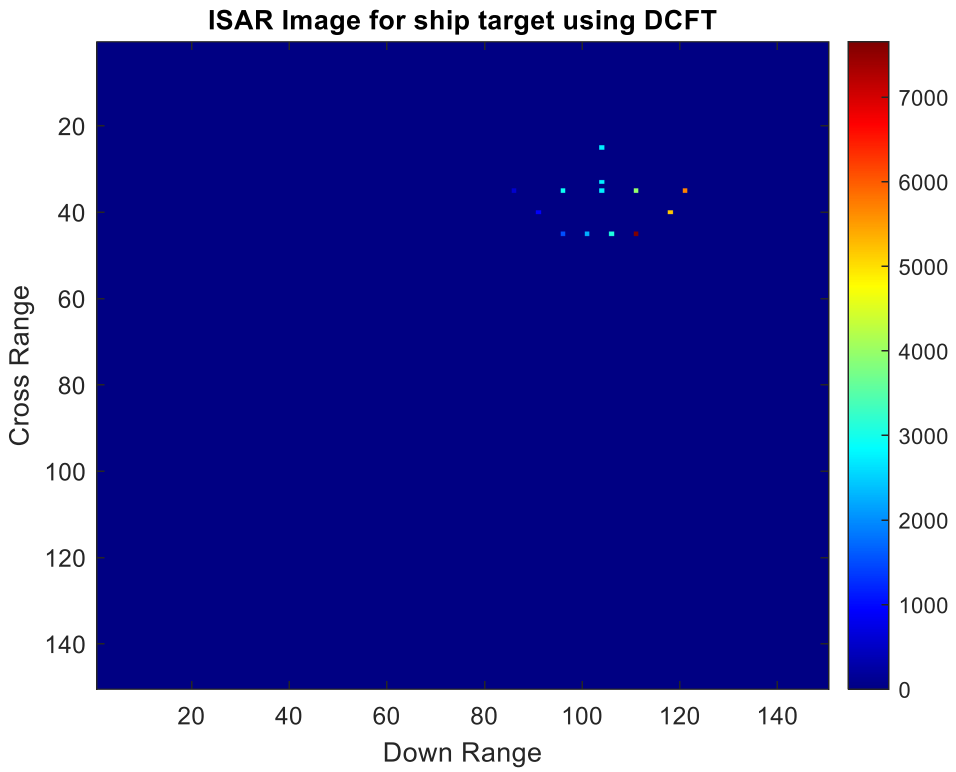

Figure 4. ISAR image using DCFT

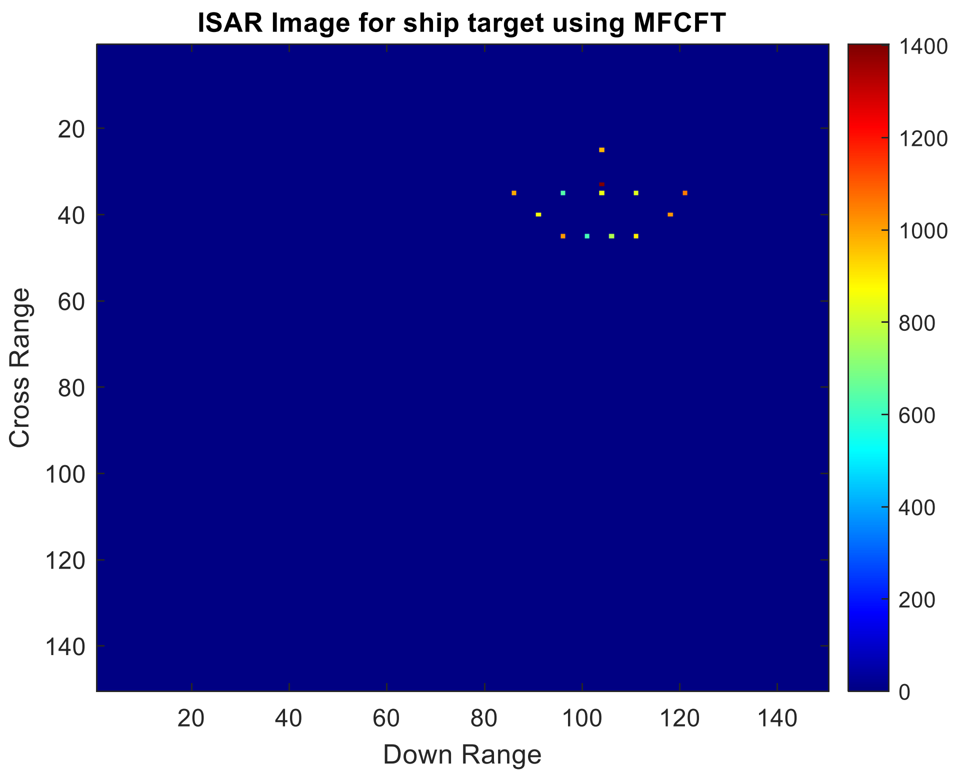

Figure 5. ISAR image using MFCFT

B. Ship target with 70 scattering points

The simulation is carried out for another ship Target with 70 scattering points. Figure.6 shows the simulated ship target with 70 scattering points. Figures.7,8 & 9 represents the ISAR images using Gabor Transform, DCFT and MFCFT respectively. From these images, one can clearly observe the improvement in CRR in case of MFCFT. The improvement in CRR and computation time is clearly shown in Table-1 and Table-2 respectively.

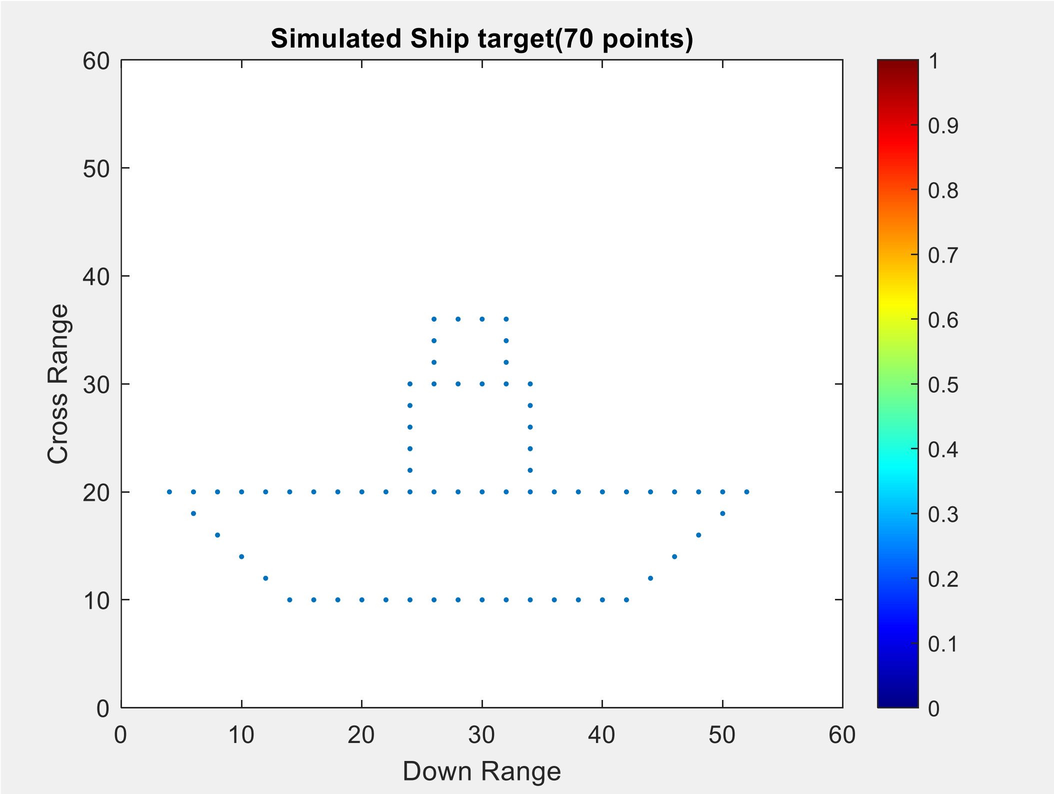

Figure 6. Simulated ship target with 70 points

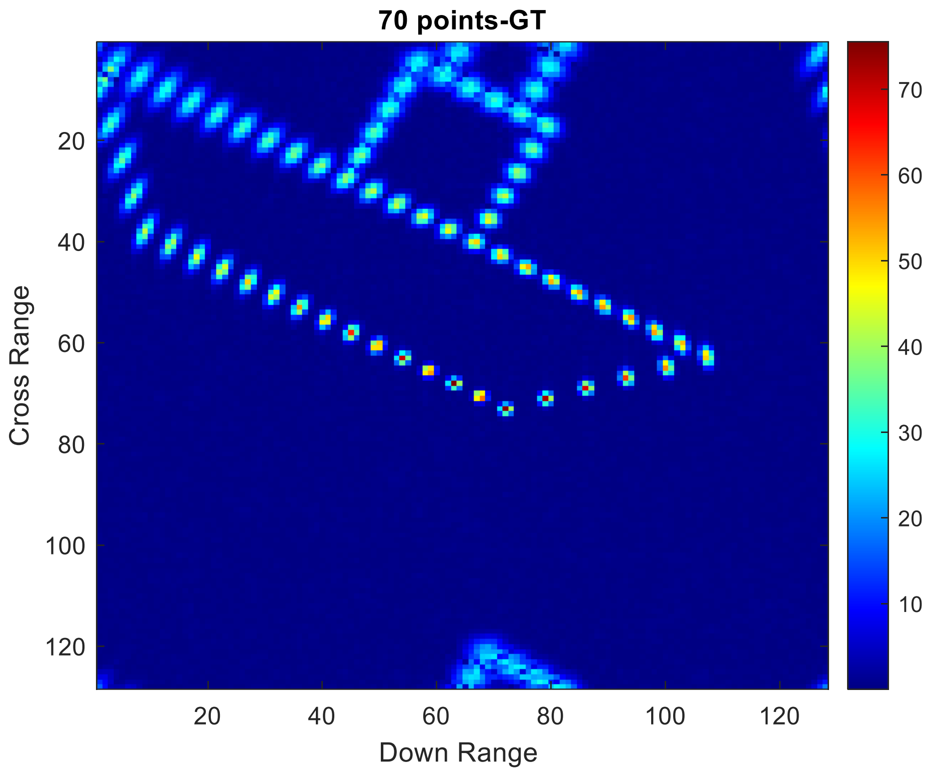

Figure 7. ISAR image using GT

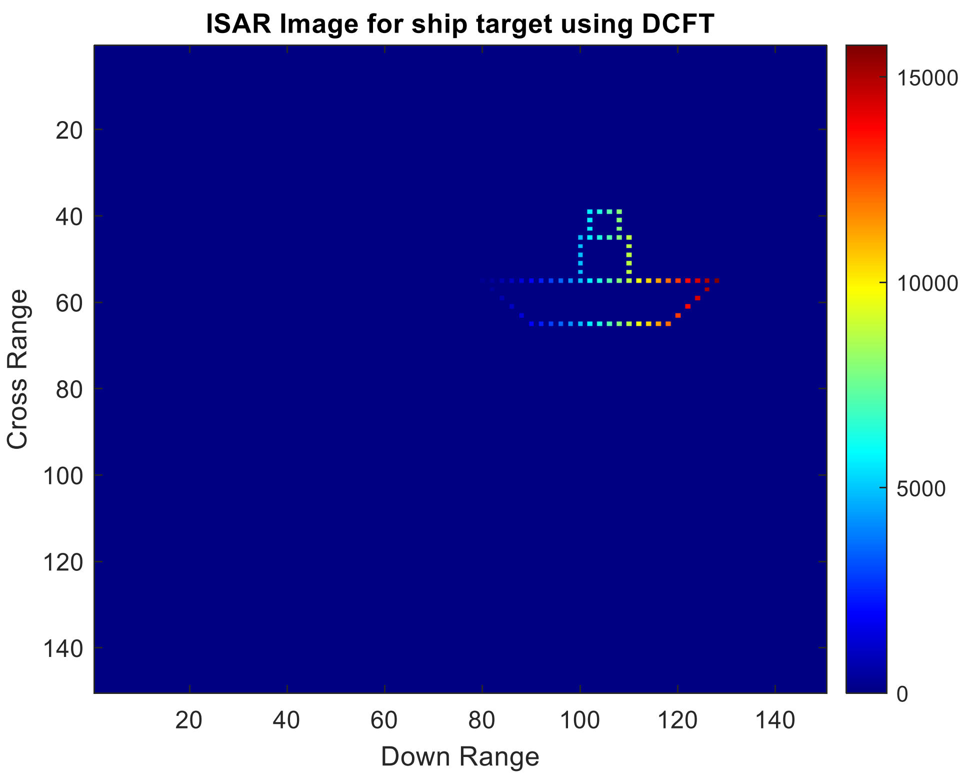

Figure 8. ISAR image using DCFT

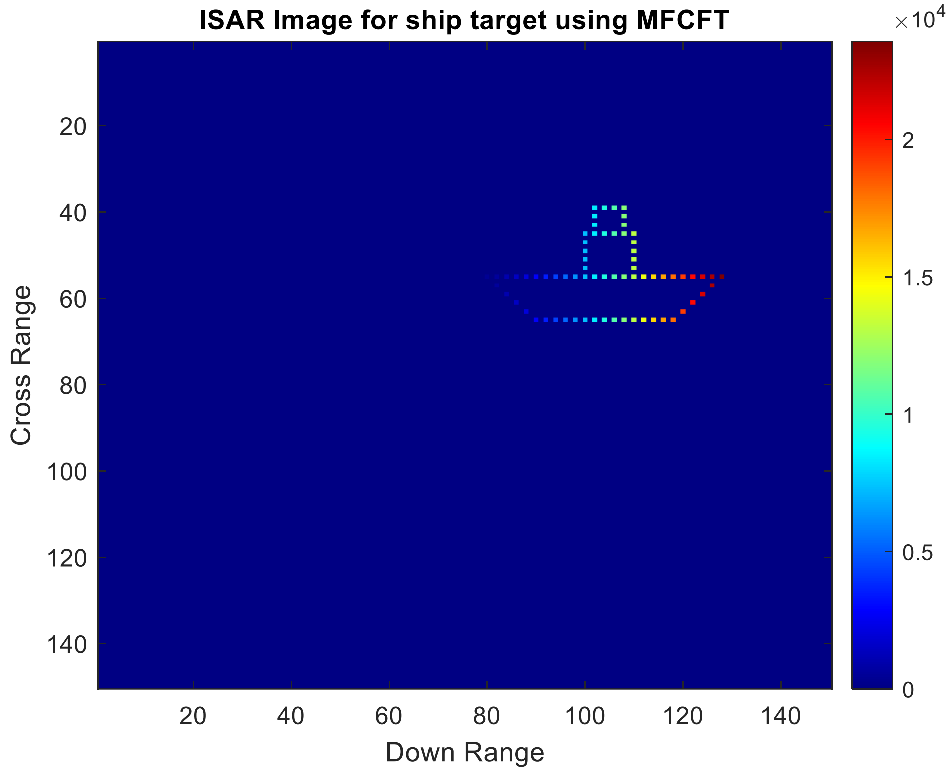

Figure 9. ISAR image using MFCFT

Table 1. Comparison of CRR for different methods

Resolution	GT	DCFT	MFCFT
DRR(m)	1	1	1
CRR(m)	1.210	1.10	1.05

Table. II: Comparison of Computation time for DCFT and MFCFT methods

Computation Time		
Algorithms	Ship(13)	Ship(70)
DCFT(minutes)	2	28
MFCFT(minutes)	1	19

5.Conclusions

In this paper, the improvement in CRR is shown for different algorithms of ISAR imaging like GT, DCFT and MFCFT. Among all these algorithms, MFCFT is found to be superior in terms of CRR and Computation time. From Table-I it is clearly observed that the CRR is 1.05m for MFCFT and is high in case of GT and DCFT. In case of Computation time, as shown in Table-II, comparison is done only between DCFT and proposed method because as the target manoeuvring is considered, the basic methods fails. When the target size is large as shown in Fig.6, it is composed of 70 scattering points, in such cases the computation time is more in DCFT than MFCFT. As the size is still large, then CT is more in DCFT when compared to the proposed method.

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