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Focused ISAR Imaging of Rotating Target in Far-Field Compact Range Anechoic Chamber

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Abstract: A case study of a modified Inverse Synthetic Aperture Radar (ISAR) imaging technique for different target geometries in the Far Field RCS measurement Compact Range is presented. The processing applied to the experimental data is a combination of two high resolution processes: dev of High Range Resolution profile (HRR) in the down range using stepped frequency waveform covering a total band of 4GHz, and the development of high resolution profile in cross-range is achieved using ISAR technique. The manuscript shows the use of Polar reformatting algorithm with Shannon reconstruction technique for correcting migration through resolution cells to obtain a better focused image of rotating targets.

Keywords: FM, ISAR, Polar, Radar Imaging, RCS measurement

1. Introduction

Radar imaging and multi-dimensional radar systems have become widely used in many areas, both military and commercial. This is due to the advent of more advanced waveform generation and signal processing techniques.

The basic principle of Inverse Synthetic Aperture Radar (ISAR) imaging is to coherently collect the wideband echo signals that are produced as the target rotates to present a change in viewing angle to the radar The resultant ISAR image produced after required processing is a representation of the spatial distribution of the reflectivity of a target (Radar Cross Section). The target's reflectivity is usually mapped onto a down-range versus cross-range plane, and is viewed as a radar image of the target [1, 2, 3 & 4].

2. Compact Range Test Setup & Data Acquisition

In order to examine the proposed ISAR imaging technique, experiments are conducted in Far-Field Compact Range Anechoic chamber. The Compact range used is employed with dual parabolic reflectors to focus the RF energy into a plane wave within a much shorter distance than would normally be required based on the spherical wave-front spreading [5].

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The imaging process includes the following main steps:

1) The target under test (spheres, trihedral corner reflectors) is irradiated with a plane electromagnetic wave of variable frequency f covering a band of 4GHz. The target is mounted on a positioner with axis of rotation perpendicular to the direction of propagation of the incoming wave (Fig. 1).

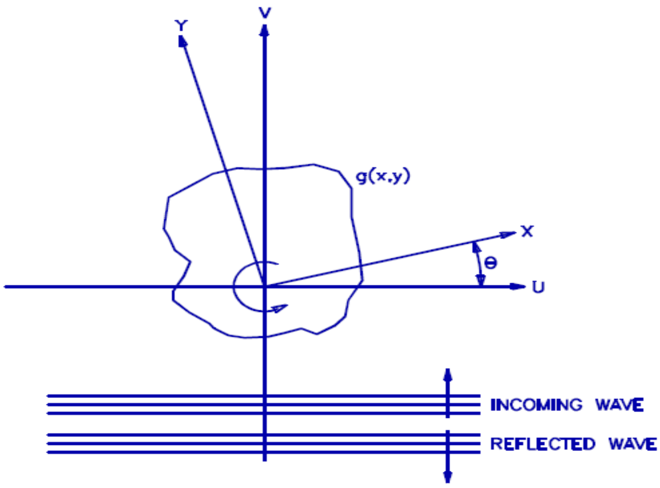


Fig. 1 Rotating target illumination by plane waveform

2) The wave reflected by the target is measured in amplitude and phase by compact range data acquisitioning system. The echo signal from a rotating target is given by [4, 5] as follows:

$$S(f,\theta)=\sum_{k=1}^{L} a_k \exp(-j\frac{4\pi f}{c}(x_k\cos\theta+y_k\sin\theta))+u(f,\theta) \qquad (1)$$

$$S(f,\theta)=\sum_{k=1}^{L} a_k \exp\left(-j\frac{4\pi f}{c}(x_k\cos(\theta)+y_k\sin(\theta))\right)+u(f,\theta)$$

where,

c	the speed of light waves,
f	transmitted frequency,
θ	rotating angle
x, y	target position

3) The received Radar Cross Section (RCS) data uniformly sampled in the frequency aspect domain (f,θ) does not correspond to the uniformly sampled data in the spatial frequency domain (f_x,f_y) due to non-linear relationship given by ($f_x=\frac{2f}{c}\sin\theta$, $f_y=\frac{2f}{c}\cos\theta$) .

3. Applied Unfocused and Focused Imaging Methods

a. Unfocused Imaging

Narrow angle approximated spatial domain ($f_x \approx \frac{2f}{c}\theta$, $f_y \approx \frac{2f}{c}$) approximately makes a Cartesian grid without use of interpolation. The required processing to obtain $s(x,y)$ from $S(f,\theta)$ is 2D-FFT. Due to the approximations made, the resulting image will not be perfect due to Motion Through Resolution Cell (MTRC) [6, 7 & 8]. Figure 2 depicts the phenomenon of Migration Through Range Resolution (MTRRC) and Migration Through Cross Range Resolution Cell (MTCRRC) for a large rotating target, which occurs if target size exceeds the following dimensions [4, 5, 7];

Maximum Dimension in Down-range: $D_{r,max} = \frac{c}{f_o\Theta^2}$ (2a)

Maximum Dimension in Cross-range: $D_{c,max} = \frac{c}{B\Theta}$ (2b)

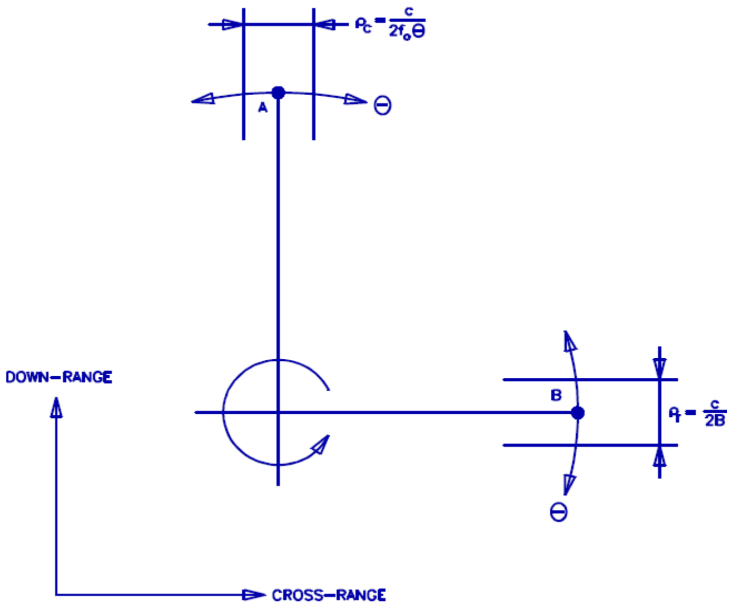


Fig. 2 MTRC phenomenon

b. Focused Imaging

Data uniformity in spatial frequency domain (f_x, f_y) is essential for application of Fast Fourier Transform algorithm or high resolution PSD estimators. Therefore, in order to generate a focused ISAR image, the received data is converted from polar-Formatted samples to Cartesian-Formatted samples with uniform spatial frequency sampling spacing using Shannon reconstruction technique [8, 9]. The technique is based on sin function interpolation as given below;

$$f(x) = \sum_x s(x) \sin c\left(\frac{x - x_n}{\Delta}\right) \quad (3)$$

where x_n is the amplitude of the available samples and Δ is the sampling space. 1-D mathematical model (Eq. (3)) is used to interpolate data in first in down-range and then in cross-range in order to convert Polar grid data into Cartesian grid data. 2D FFT is applied on Cartesian grid data that compresses the data in range and azimuth to achieve the desired resolution and focused image. FFT being computationally efficient is the first choice in real time radar imaging applications.

4. Experimental Results and Discussion

The following three tests are conducted in compact range while the results are summarized in Table 1.

Table 1 Tests (1, 2, 3) Result Summary

Parameters	**Test Type**		
	Two spheres	**4 corner Reflectors**	**5 Corner reflectors**
Bandwidth (GHz)	4	4	4
Aspect Angle Span	16°	60°	60°
Range Resolution (cm)	3.75	3.75	3.75
Cross Range Resolution (cm)	3.25	0.89	0.89
Target Size Limits $D_{r,max} \times D_{c,max}$ (cm)	24×27	2×7	2×7
Actual Target Area **(** $D_r \times D_c$ **) (cm)**	5×34	40×70	50×50
MTRRC	2 cells	10 cells	7 cells
MTCRRC	0 cells	24 cells	30 cells
Image Produced by Narrow-Angle Approximation Approach	Reasonably Focused	Unfocused	CR5 is well focused, CR(1,2,3,&4) are unfocused
Image Produced by Polar Reformatting using Shannon Reconstruction	Both spheres are Highly Focused	All corner reflectors are Well Focused	CR(1,2 &5) are well focused while CR(3,4) are still Blurred

Test 1: Two Spheres:

In this test two Spheres of diameter 3cm and 5cm respectively are placed in same range cell and are separated in cross range by 30 cm. The contour plots of resultant images are shown in Fig. 3. Due to negligible MTRRC and 0 MTCRRC, image obtained by narrow angle approximation and Shannon reconstruction are of almost same quality.

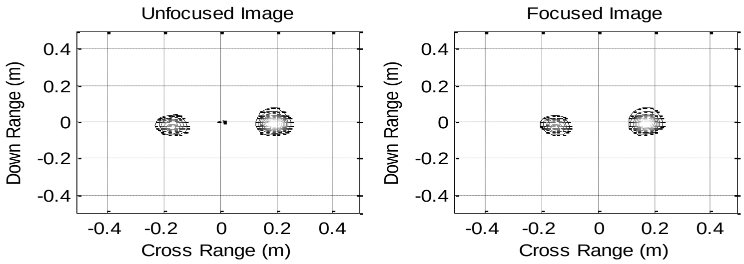
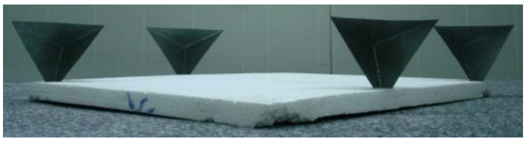


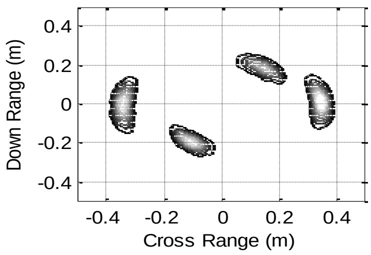
Fig. 3 Target geometry with two spheres

Test 2: Four Trihedral Corner Reflectors

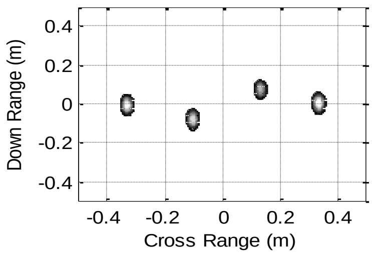
In this experiment four trihedral corner reflectors are arranged in parallelogram geometry as shown in Fig. 4a. The resultant images are shown in Figs. 4b & 4c. Due to high MTRRC and MTCRRC image obtained by narrow angle approximation is blurred. Shannon Reconstruction created a high quality focused image with this geometry of target arrangements.



(a) Test 2 setup



(b) Unfocused image

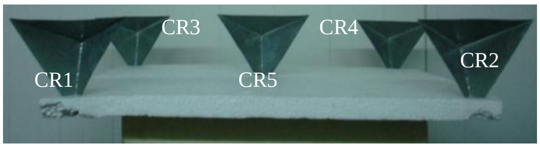


(c) Focused image

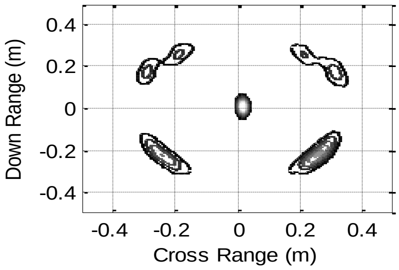
Fig. 4 Four Trihedral Corner Reflectors

Test 3: Five Trihedral Corner Reflectors

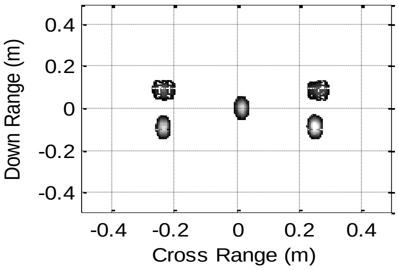
Five trihedral corner reflectors arrangement is shown in Fig.5a. The resultant images are shown in Figs.5b & 5c. In addition to high MTRRC and MTCRRC, reflections obtained from Corner Reflectors CR3 & C4 are weakened due to shadowing effects produced by CR1 & CR2 respectively. Image obtained by narrow angle approximation is blurred and distorted. However, Shannon Reconstruction created a good quality focused image with this geometry of target arrangements but method could not remove the shadowing effect completely.



(a) Test 3 setup



(b) Unfocused image



(c) Focused image

Fig.5. Five Trihedral Corner Reflectors

5. Conclusion

A method for focusing ISAR images based on polar reformatting technique using Shannon reconstruction is presented. Algorithm is applied on experimental data obtained from different target geometries in the Far Field RCS measurement Compact Range. In test1, where MTRC was negligible, both narrow band approximation and Polar reformatting approach gave similar results. In test2, the blurring effect produced by MTRC phenomenon for the four trihedral corner reflectors, CRs, (arranged in Parallelogram geometry) was fully corrected and highly focused by Polar reformatting. However, the blurring effect of corner reflectors (CR3 & CR4) was partially corrected by polar reformatting due to weak reflections received from the reflectors with severe MTRC (30 cells). This happened due to the signal shadowing in target geometry, as the corner reflectors (CR3 & CR4) were in same cross range cells behind the CR1 & CR2 respectively.

6. Acknowledgements

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