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An Efficient Classification Method for Inverse Synthetic Aperture Radar Images

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***Abstract*—**This paper proposes an efficient method to classify inverse synthetic aperture (ISAR) images. Because ISAR images can be translated and rotated in the 2-dimensional image place, invariance to the two factors is indispensable for successful classification. The proposed method achieves invariance to translation and rotation of ISAR images using a combination of two-dimensional Fourier transform, polar mapping and correlation-based alignment of the image. Classification is conducted using a simple matching score classifier. In simulations using the real ISAR images of five scaled models measured in a compact range, the proposed method yields classification ratios higher than 97 %.

***Keywords*—**Radar, ISAR, radar target classification, radar imaging.

I. Introduction

INVERSE synthetic aperture radar (ISAR) imaging is a technique to generate a two-dimensional (2D) high-resolution image of a target [1]. Because ISAR image can be obtained regardless of weather and day-night conditions and it provides useful 2D features, ISAR has been applied to numerous classification areas [2]-[3]. Classification of ISAR image is composed of two phases: training and test phases. In the training phase, a training database of ISAR images is constructed using the images derived at several aspect angles and in test phase, the ISAR image of an unknown target is classified using the ISAR image stored in the training database. However, classification of ISAR images is very difficult due to the translational and the rotational variations depending on the orientation between the radar and a target for measurement. Therefore, an efficient classification method that is invariant to rotation and translation is required.

In this paper, we propose a new classification method which utilizes two important characteristics of the 2D Fourier transform (2D FT). Because the 2D image derived from the 2D FT of the ISAR image is the spectrum of the original image, the translation in the ISAR image is the simple phase multiplication in the 2D FT image. In addition, because the rotation of the ISAR image around an unknown rotation center (RC) is equivalent to the rotation around the zero frequency, an exhaustive search procedure is not required to find the RC. Therefore, the rotation angle of the ISAR image can be obtained by polar mapping the 2D FT image and finding the relative shift in θ direction using the correlation. In the classification, we use

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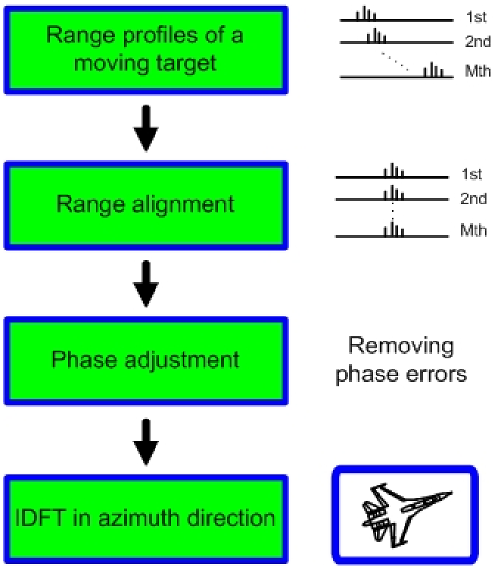


Fig. 1 Range-Doppler algorithm [4]

a simple matching score classifier between the train and the test polar mapped image aligned in θ direction. The target yielding highest matching score value was selected as the unknown target. In experiment, we constructed the scaled model of the six real targets and the radar cross section (RCS) of each target was measured in the X-band compact range. Then, ISAR images of each target were collected at several aspect angles. Classification ratios derived using the measured ISAR images and the proposed methods were higher than 97 % regardless of the location of the RC in the image domain, proving the efficiency of the proposed method.

II. Principle of ISAR Imaging and Proposed Method

A. Range-Doppler Algorithm for ISAR Imaging

The most widely used method for ISAR imaging is the range-Doppler algorithm which is composed of four steps: generation of range profiles of a moving target at several aspect angles, range alignment, phase adjustment and cross-range compression using inverse discrete FT (IDFT) in azimuth direction [1, 4] (Fig. 1). Range profiles are provided by the range compression using either matched filtering of wideband chirp signals or inverse FT of wideband stepped-frequency signals. Translational motion compensation composed of range alignment and phase adjustment is conducted to remove the effect of the translational motion of a target and the IDFT in azimuth direction positions scatters in the vertical axis of ISAR.

In this paper, we use the range-Doppler imaging without translational motion compensation [5] because the main topic of this paper is the classification of ISAR images. ISAR images used to demonstrate the efficiency of the proposed method are derived using scaled models that are stationary in the compact range. Assuming a plane wave, the received echo signal from a target for a frequency *f* and aspect angle θ can be expressed as [6]

$$I(f,\theta) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \rho(x,y)\exp\left[-\frac{j4\pi f}{c}\left(x\cos\theta + y\sin\theta\right)\right]dxdy\,, \qquad (1)$$

where $\rho(x, y)$ is the RCS at (x, y), and c is the speed of light. Assuming $f_x = 2(\cos\theta)/\lambda$ and $f_y = 2(\sin\theta)/\lambda$, (a) can be can be expressed as

$$I(f_x,f_y) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \rho(x,y)\exp\left[-j2\pi\left(f_x x + f_y y\right)\right]dxdy\,. \qquad (2)$$

$\rho(x, y)$ mapped on (x, y) domain is the ISAR image and can be derived by simple 2D inverse FT as follows:

$$\rho(x,y) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} I\left(f_x,f_y\right)\exp\left[j2\pi\left(f_x x + f_y y\right)\right]df_x df_y\,. \qquad (3)$$

because we use wide angles for high resolution ISAR image, (2) is not rectangular and this can defocus the ISAR image seriously. Therefore, 2D polar-mapping was conducted to derive to drive equally-spaced samples in the frequency domain [2].

B. 2D FT of ISAR Image

To estimate the relative rotation angle between two ISAR images, the RC must be fixed. However, estimating the RC of the ISAR image is very difficult because RC is different depending on the complicated motion of the target. Therefore, a method that provides the rotation angle between two ISAR images regardless RC is required.

In this paper, we use the two characteristics of the ISAR image in the 2D frequency domain; the shift and the rotation in the image domain are the multiplication by the complex exponential term and the rotation in the frequency domain, respectively. 2D FT of an image is represented by

$$F(u,v) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f\left(x,y\right)e^{-j2\pi ux}e^{-j2\pi vy}\,, \qquad (4)$$

where $F(u,v)$ is the FT of the image $f(x,y)$. The shift in the image domain is transformed to the phase multiplication as follows:

$$\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f\left(x-x_0,y-y_0\right)e^{-j2\pi ux}e^{-j2\pi vy}dxdy = \exp(-j2\pi(x_0 u + y_0 v))F(u,v) \qquad (5)$$

If only the absolute value of (5) is used for classification, the translational invariance can be acquired. In addition, the rotational characteristic of 2D FT is represented as follows [2]:

$$F(\Omega,\Phi) = \int_{-\infty}^{\infty}\int_{-\pi}^{\pi} f\left(r_{im},\theta_{im}\right)e^{-j2\pi r_{im}\Omega\cos(\Phi-\theta_{im})}r_{im}dr_{im}d\theta_{im}\,, \qquad (6)$$

where $F(\Omega,\Phi)$ and $f\left(r_{im},\theta_{im}\right)$ are the polar forms of $F(u,v)$ and $f(x,y)$ (see [7] for the detailed procedure). Because RC in $F(\Omega,\Phi)$ is at (0, 0), estimation of RC is not required.

C. Classification using Polar Mapped Images

Polar mapping is an efficient method to estimate the rotation angle by transforming the rotation in in (u,v) to the translation in (r, θ) domain [8]. Polar mapping of 2D FT image is conducted

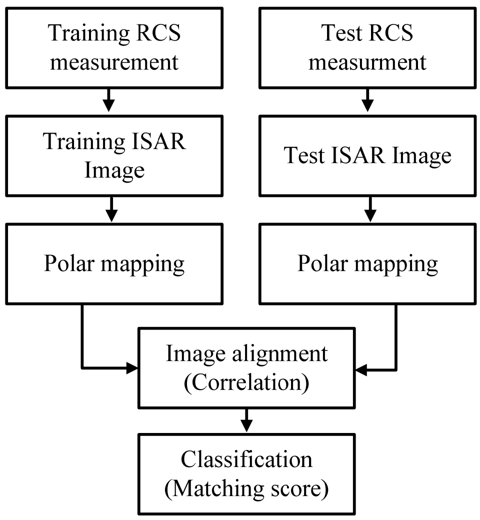


Fig. 2 Classification procedure

by positioning the pixel values in (u_{mn},v_{mn}) to corresponding polar grids (r_m, θ_n) using the following relationship:

$$(u_{mn},v_{mn}) = (u_c,v_c) + (r_m\cos\theta_n, r_m\sin\theta_n)\,, \qquad (7)$$

where (u_c,v_c) is the RC which is (0, 0) in 2D FT image. r_ms are the radius of the sampling circle m and θ_ns are the nth angle defined as follows:

$$r_m = R_{\min} + (m-1)\Delta r\ ,\ \theta_n = -\pi + (n-1)\Delta\theta\,, \qquad (8)$$

and

$$\Delta r = \frac{R_{\max} - R_{\min}}{N_r - 1}\,,\ \Delta\theta = \frac{2\pi}{N_\theta - 1}\,, \qquad (9)$$

where R_{max} and R_{min} are the maximum and the minimum radius of the polar grids, N_r and N_θ are the number of sampling grids in r and θ directions.

Because the polar mapping transforms the 2D rotation to the 1D translation in θ direction (see [8]), the test polar mapped images can be successfully aligned by finding the maximum correlation and this can improve the classification result considerably in the classification stage (see Fig. 2). For a shift τ, correlation between the mth row of a training polar mapped image (Tr_m**)** and that of a test image (Te_m) is defied by

$$Cor_m(\tau) = \sum_{n=0}^{N_\theta - 1} Tr_m[n]Te_m[n-\tau]. \qquad (10)$$

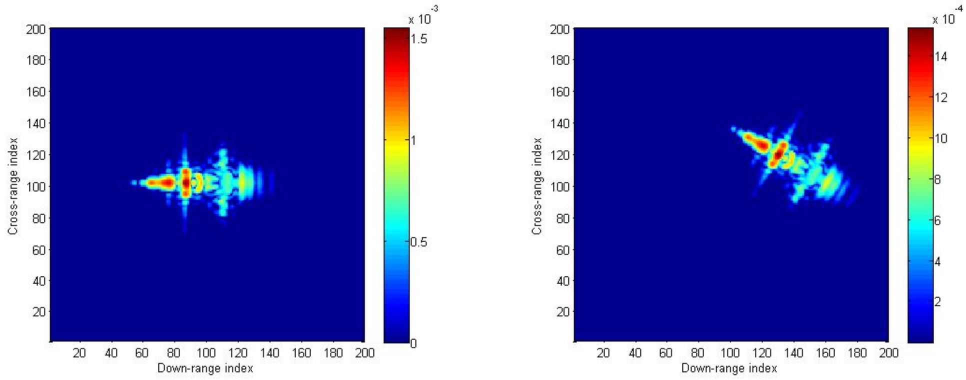
The correlation value used as a cost function for alignment is the sum of Cor_ms for all rows as follows:

$$Cor = \max\left\{\sum_{m=0}^{N_r - 1} Cor_m(\tau)\right\}. \qquad (11)$$

Then, classification is conducted using the following matching score between the training and the test polar mapped image aligned using (11):

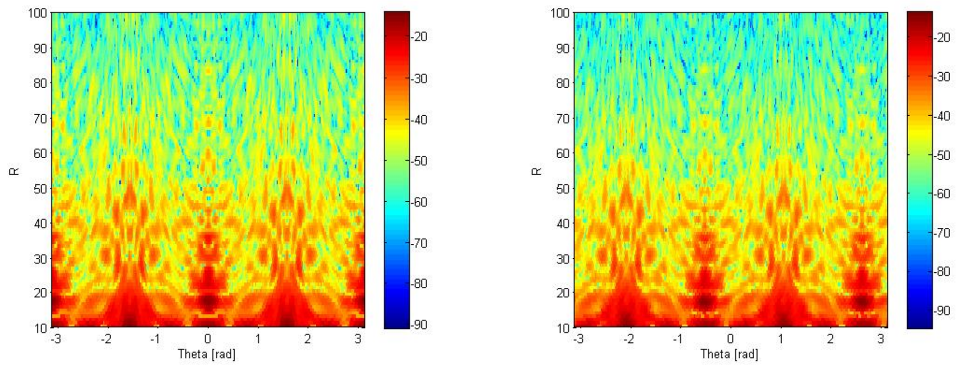
$$MS = \left\{\sum_{n=0}^{N_\theta - 1}\sum_{m=0}^{N_r - 1} TR(m,n)TE(m,m)\right\} \qquad (12)$$

The unknown test target is classified as the target whose polar mapped image yields the maximum *MS* with the test polar mapped image. Compared with the correlation-based method



(a) ISAR image of F4 aircraft model (b) Translated and rotated version of (a)

Fig. 3 Two ISAR images of F-22 aircraft



(a) 2D FT image of Fig. 3a (b) 2D FT image of Fig. 3b

Fig. 4 2D FT image of Fig. 3

proposed in [9], this method provides higher classification ratios due to the combination of the correlation and the matching score .

III. Classification Results

Classification was conducted using the RCS data measured in the X-band 4GHz compact range of POSTECH and six aircraft models: F4, F14, F16, F22, F117 and Mig29. The measured RCS data were processed to generate ISAR images for aspect angle from 0° to 180° with an increment of 1° and the training data were constructed for every 5° angular increment. The remaining images were used for classification and classification was conducted using a simple correlation (Fig. 2). The angular variation to obtain ISAR images was 30°, therefore, polar reformatting was conducted to derive the focused ISAR image. In polar mapping, N_r = 100 and N_θ = 100 were used.

An F-22 ISAR image and its shifted and rotated version (Fig. 3) were formed and their 2D FT images (Fig. 4) were derived to prove the translational and the rotational characteristics of 2D FT. Fig. 3(a) was shifted by (-30, 30) and rotated by 30° clockwise to yield Fig. 3(b). Comparison between Fig.4a and b demonstrates the translational and rotational characteristics of 2D FT; the translation was removed by taking the absolute value of the 2D FT image and the same amount of rotation occurred in

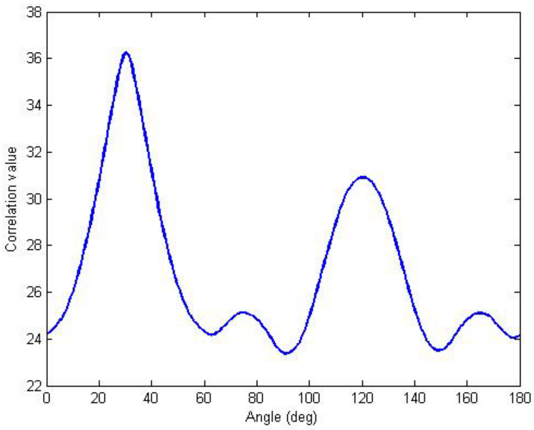


Fig. 5 Correlation values versus rotation angle

2D FT image with RC at (0,0). Therefore, the maximum correlation value occurred at the rotation angle = 30° (Fig. 5).

Classifications for various signal-to-noise-ratio (SNR) values were conducted to demonstrate the efficiency of the proposed method. To simulate the effect of SNR, additive white Gaussian noise (AWGN) was added to the measured RCS data and SNR was varied from 10 to 30 dB in an increment of 5 dB. Because of the random nature of AWGN, the classification was repeated 10 times at each SNR and the average correct classification P_c was used as the classification result. P_c was defined as follows:

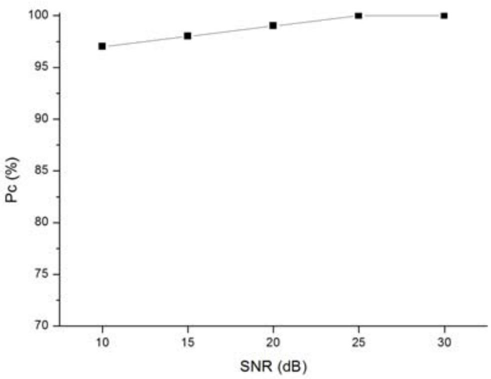


Fig. 6 Classification result for various SNRs

$$P_c = \frac{\text{No. of correct classifications}}{\text{No. of test samples}}. \quad (12)$$

Classification results in Fig. 6 demonstrate the efficiency of the proposed method. P_cs for all SNR values were close to 100 %. The lowest P_c was obtained at SNR = 10dB and was equal to 97.69 % and for SNR = 25 and 30, P_cs = 100 % were obtained. Considering the training polar mapped images sampled at 5° increment, it can be concluded that the proposed classification method provided very high classification results using a small number of training images (37x 5 = 185).

IV. Conclusion

In this paper, we proposed an efficient method for the classification of ISAR images. The proposed method utilized the characteristics of the 2D FT to obtain the translational and the rotation invariance. Using the characteristic that the translation in the image domain corresponds to the phase multiplication in the frequency domain, the translational invariance was achieved by simply taking the absolute value of the 2D FT image. The rotational invariance was obtained by a combination of 2D FT, polar mapping, correlation and matching score classifier. Because the rotation around an unknown RC in the image domain corresponds to the rotation around the zero frequency in the frequency domain, RC was automatically found. Then, polar mapping of the 2D FT image transformed the rotation to the translation and the correlation was used to align ISAR images. A simple matching score classifier was used for final classification of the ISAR image. Experimental results using the measured ISAR image of six aircraft models provided classification ratios higher than 97% for SNRs = 10, 15, 20, 25 and 30 dB.

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References

[1] C. C. Chen and H. C. Andrews, “Target-motion-induced radar imaging,” *IEEE Trans. Aero. and Electr. Syst.*, vol. 16, no. 1, pp. 2-14, Jan. 1980.
[2] D. L. Mensa, *High Resolution Radar Cross Section Imaging,* Artech House, Norwood, 1991.
[3] A. Zyweck and R. E. Bogner, “High-resolution radar imagery of the Mirage III aircraft,” *IEEE Trans. Antennas Propag*., vol. 42, no. 9, pp. 1356-1360, 1994.
[4] S. H. Park, H. T. Kim, K. T. Kim and J. I. Park, “An efficient range alignment algorithm method for long-range ISAR imaging,” *2009 Int. Radar Conf.*, pp. 1-5, Oct. 2009.
[5] L. Xi and L. Guosui, J. Ni, “Autofocusing of ISAR images based on entropy minimization,” *IEEE Trans. Aero. and Electr. Syst.*, vol. 16, no. 1, pp. 2-14, Jan. 1980.
[6] S. H. Park, J. H. Jung, H. T. Kim and K. T. Kim, “Construction of 2D training database based on high frequency RCS prediction methods,” *Microw. Opt. Techn. Let.*, vol. 53, no. 1, pp. 223-229, Jan. 2011.
[7] S. H. Park, K. T. Kim and H.-T. Kim, "Cross-range scaling algorithm for ISAR images using 2D Fourier transform and polar mapping", *IEEE Trans. on Geosci. Remote Sens.*, vol. 29, issue 2, pp. 868 - 877, Feb. 2011

[8] K. T. Kim, D. K. Seo and H. T. Kim, "Efficient classification of ISAR images," *IEEE Trans. Antennas Propag*., vol. 53, no. 5, pp. 1356-1360, May 1994.
[9] S. H. Park, K. T. Kim and H. T. Kim, "Efficient classification of ISAR images using 2D Fourier transform and polar-mapping," *Korea Inst. Mil. Sci. Tech. 2012 Annual Conf.*, pp. 635-638, Jun. 2010.