Classification of ISAR Images Using VIRAF Software

Seung-Jae Lee, Seong-Jae Jeong, Myung-Jun Lee, and Kyung-Tae Kim
POSTECH, Radar & Electromagnetic Signal Processing Lab.

Presenter: Seung-Jae Lee
Contents

1. Inverse synthetic aperture radar (ISAR) image

2. Motivation

3. Classification algorithms using ISAR images

4. Classification results

5. Discussion & Conclusion
**ISAR image**

- **ISAR imaging**
  - Generation of radar images based on ISAR configurations where the radar stays stationary while the target is in the motion
  - Collection of the received radar signals: a specific frequency bandwidth, a number of aspect angles
  - Image formation: range-Doppler algorithm based on two-dimensional (2D) Fourier transform (FT)
Motivation

- Commercial Software
  - Assistance to mitigate the practical limitation
  - It requires only a computer to obtain the realistic ISAR image
  - FEKO, computer simulation technology (CST), virtual aircraft framework (VIRAF)

  - An efficient graphical user interface (GUI) for ISAR/SAR imaging
  - Acquisition of the DBs for classification tasks in a short amount of time
Motivation

Purpose of this study

- Investigation of the availability of the VIRAF software for classification of ISAR images
- Generation of ISAR images of various targets
  - Well-known physical optics (PO) and physical theory of diffraction (PTD) techniques in the VIRAF software
- Analysis of the classification performance using two different classification methods
  - Nearest neighbor classifier (NNC)
  - Polar-mapping (PM) method with two-dimensional (2D) Fourier transform (FT)
Classification algorithms using ISAR images

- **Preprocessing**

  - **Segmentation**
    
    - Only target response is extracted from the entire 2D image plane
    - Target pixels that have signal levels above the threshold are selected

    \[
    s(x,y) \text{: 2D ISAR image in dB scale} \quad x=1,2,...,M \quad y=1,2,...,N
    \]

    \(x, y\): down-range and cross-range dimension in the 2D image plane

    \(N, M\): the number of pixels in each dimension

  - **Normalization**

    - Remove signal level variation, arising from different distances between a radar and targets

    \[
    s_n = \frac{\sum_{i=1}^{M} \sum_{j=1}^{N} s_{th}(i, j)}{\sum_{i=1}^{M} \sum_{j=1}^{N} s_{th}(i, j)}, \quad s_{th}(i, j) \text{: ISAR image after segmentation}
    \]
Classification algorithms using ISAR images

**Nearest neighbor classifier (NNC)**

- Euclidean distances between the preprocessed training ISAR images and the unknown ISAR image are first computed as follows:

\[
d_{\text{min}} = \min_d d_k, \quad d_k = \| s_{n,k} - s_{n,te} \|
\]

where:

- \( s_{n,k} \): \( k \)-th training ISAR image after preprocessing,
- \( s_{n,te} \): unknown ISAR image after preprocessing

- The true target class \( c \) is determined as the class of the training ISAR image having the smallest Euclidean distance \( d_{\text{min}} \)
Classification algorithms using ISAR images

- Polar mapping method with 2D Fourier transform (PM+FT)

- Efficient classification method using the PM technique and the characteristics of 2D FT
- 2D FT image has an invariance to the translation of ISAR image
- Resampling the 2D FT image using the PM technique into two orthogonal coordinates, radius $r$ and angle $\theta$

$\Delta r$: resampling interval in $r$ direction
$\Delta \theta$: resampling interval in $\theta$ direction

$R_{\text{max}}$: radius of the largest circle
$R_{\text{min}}$: radius of the smallest circle

< Polar grid >

< Geometry of polar image >
Classification algorithms using ISAR images

- Polar mapping method with 2D Fourier transform (PM+FT)
  - Polar-mapped image $\mathcal{I}_p (r, \theta)$ can be used as a feature
  - Rotation of ISAR image $\rightarrow$ Translation of polar-mapped image in $\theta$ direction
    - This can be solved using correlation-based alignment

< Original ISAR image of F16 >   < FT image of F16 >   < Polar-mapped image of F16 >
## Classification algorithms using ISAR images

### Polar mapping method with 2D Fourier transform (PM+FT)

#### Algorithm summary

1. **Preprocessing**
2. **Upsampling** of the preprocessed ISAR images, construction of 2D FT images, construction of polar-mapped images from the 2D FT images, and sampling $A_{tr}$ and $A_{te}$ from each polar-mapped image for the alignment.
3. **Alignment** of the test image by using the simple correlation coefficient between $A_{tr}$ and $A_{te}$, compression of polar-mapped images by using the 2D principal component analysis (PCA), and the classification of the compressed image by using NNC.

---

Classification results

**Setup for classification**

- Four different 3D CAD aircraft models: Gripen, F16, Mig25, and Yf23

- “**hourglass plot**” option in the VIRAF software to obtain the scattered field data sets by using only rotational component of targets, without translational motion

**PO+PTD techniques**
Classification results

- Acquisition of the scattered field datasets

- ISAR geometry for the acquisition of the scattered field datasets
- Target whose heading direction is $x'$ was laid on $x'^* - y'$ plane
- Elevation angle $\theta'$ was fixed at 90°
- ISAR images were generated only varying azimuth angle $\phi'$
- Center azimuth angle $\phi'_{\text{c}} = 0° - 180°$ with steps of 1°
- Whole $181 \times 4$ (the number of target) = 724 ISAR images

- Imaging parameters for one ISAR image -

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of frequencies ($N$)</td>
<td>101</td>
</tr>
<tr>
<td>Number of angles ($M$)</td>
<td>101</td>
</tr>
<tr>
<td>Center frequency (GHz)</td>
<td>10</td>
</tr>
<tr>
<td>Frequency bandwidth (MHz)</td>
<td>500</td>
</tr>
<tr>
<td>Angular width of $\phi'$ (Deg)</td>
<td>2.86</td>
</tr>
</tbody>
</table>
Classification results

- Generation of ISAR images
  - 2D windowing and inverse fast FT (IFFT) [built-in functions in the MATLAB program]
  - Two different windows [blackman window and hanning window]
  - Down-range and cross-range resolutions = 0.3m

- ISAR images using blackman window at $\varphi \downarrow \phi' = 45°$

Quite different scattering mechanisms, resulting from the scattering physics of each target
Classification results

**Generation of ISAR images**

- 2D windowing and inverse fast FT (IFFT) [built-in functions in the MATLAB program]
- Two different windows [blackman window and hanning window]
- Down-range and cross-range resolutions = 0.3m

- ISAR images using hanning window at $\phi \downarrow c^\uparrow = 45^\uparrow$

Quite different scattering mechanisms, resulting from the scattering physics of each target
Classification results

● Construction of databases (DBs)

◆ Training DB
- Uniform sampling across $\varnothing \subset c^r$ with an increment of $5^r$
- The number of total training ISAR images $= 37 \times 4 = 148$

◆ Test DB
- Remaining 576 ISAR images

Classification accuracy $\mathcal{P}\downarrow c = \mathcal{N}\downarrow c / \mathcal{N}\downarrow T \times 100(\%)$

$\mathcal{N}\downarrow T$ = total number of test ISAR images
$\mathcal{N}\downarrow c$ = the number of correctly classified ISAR images
Classification results

- Classification accuracies of ISAR images obtained using the two different windows versus the signal-to-noise ratio (SNR)

- Very reliable classification performance
- Reliable DBs for the classification of ISAR images
Discussion & Conclusion

- Windowing and IFFT can be also performed by using “FFT/IFFT” function in the VIRAF software

- Very similar 2D distributions of the dominant scattering centers
- “FFT/IFFT” function in the VIRAF software can also be effectively used for the construction of DBs
Discussion & Conclusion

Conclusion

- We presented the classification of ISAR images using the VIRAF software

- The classification of ISAR images using the VIRAF software can provide a reliable performance

- The VIRAF software are believed to have good potential in the classification of ISAR images
Reference


Thank You

E-mail: jelline15@postech.ac.kr