Introduction

Microwave radar : Applicable to adverse weather or darkness

SAR(Synthetic aperture radar) : High-resolution imaging method

Target recognition with SAR imagery :

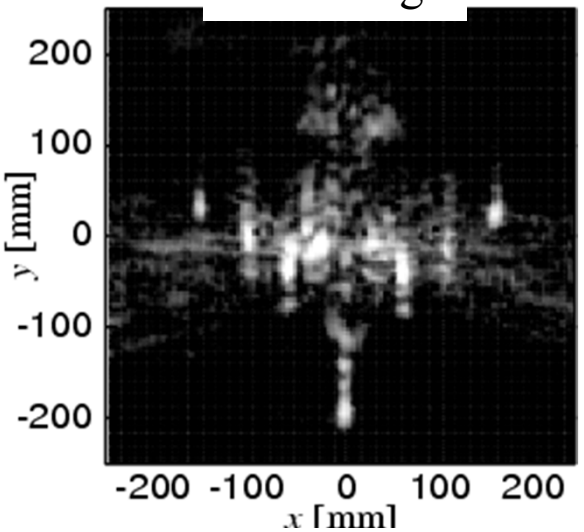
A great deal of experience is required because SAR image is definitely different from optical image

⇒ ATR(Automatic Target Recognition) method is in demand

Optical image

SAR

SAR image



Conventional ATR Techniques

Traditional ATR methods for SAR imagery

Neural Network based approach

- [1] C. M. Pilcher *et al.*, *IEEE Trans. Aerosp. Electron. Syst.*, 2011
  ⇒ Classification employing range profile data
- [2] M. Martorella, *et al.*, *IEEE Trans. Aerosp. Electron. Syst.*, 2011
  ⇒ Exploiting ISAR images with full polarimetric data

Other ATR approach

- [3] Q. Zhao, *IEEE Trans. Aerosp. Electron. Syst.*, 2001
  ⇒ SVM (Support Vector Machine) based classification

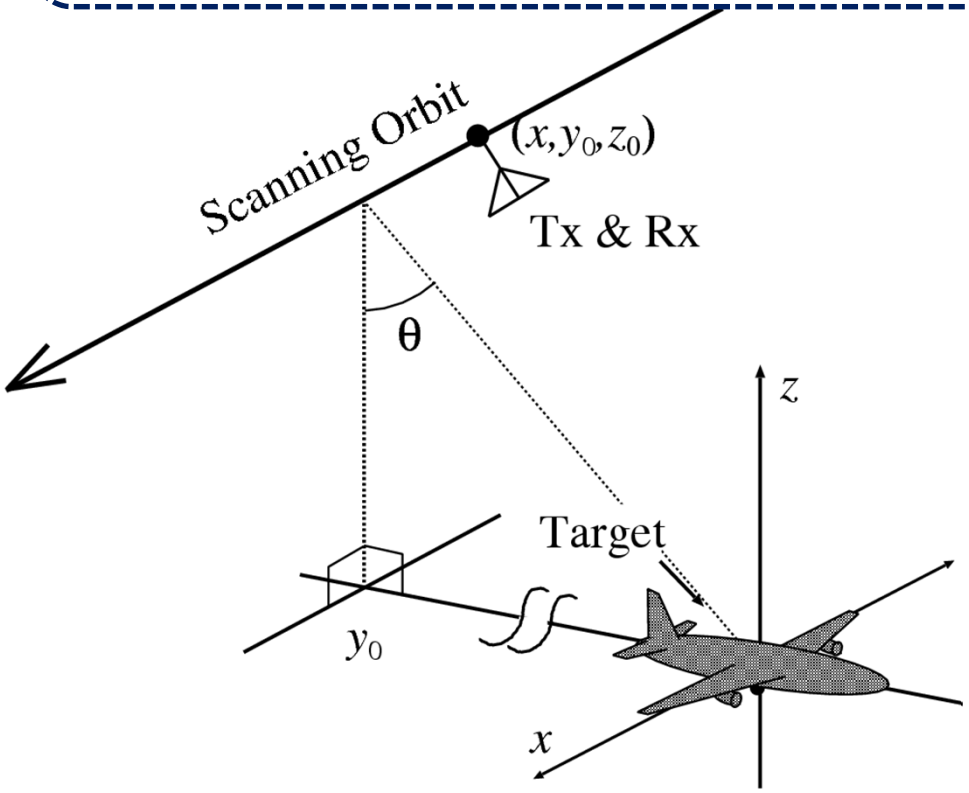
Problem in traditional methods

Inaccurate classification in the case of
strong noisy situations or observation angle errors

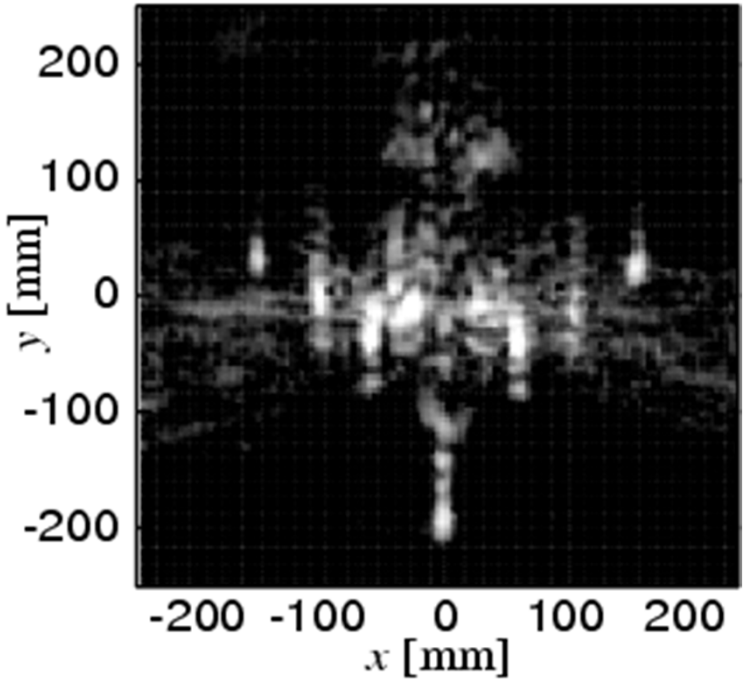
⇒ More robust ATR method is proposed here !

System Model

- Mono-static radar system
- Targets with arbitrary shapes
- Transmitted signal : Frequency sweeping (complex value)
- SAR image generation : Back projection algorithm
- Binarization method: Otsu's discriminant analysis method



SAR image



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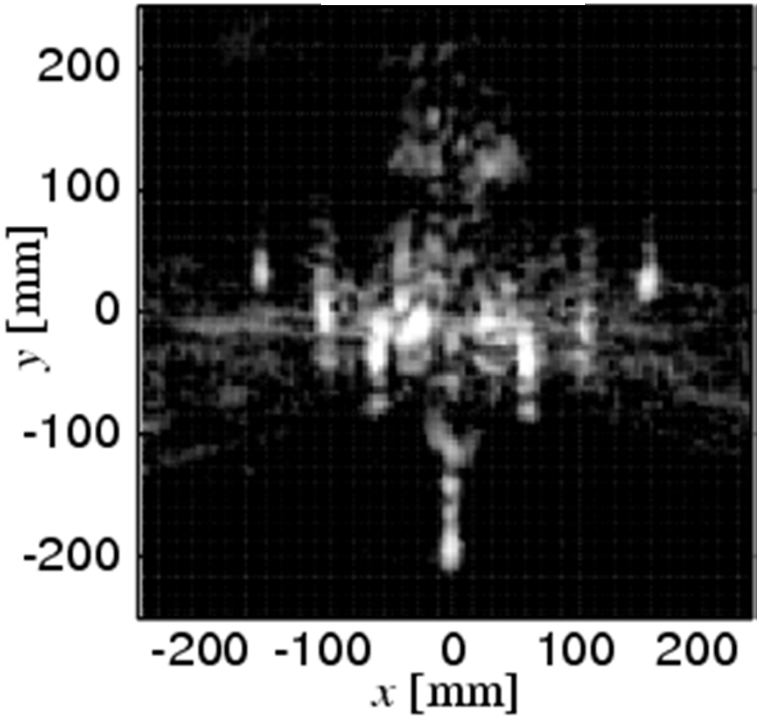
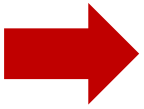
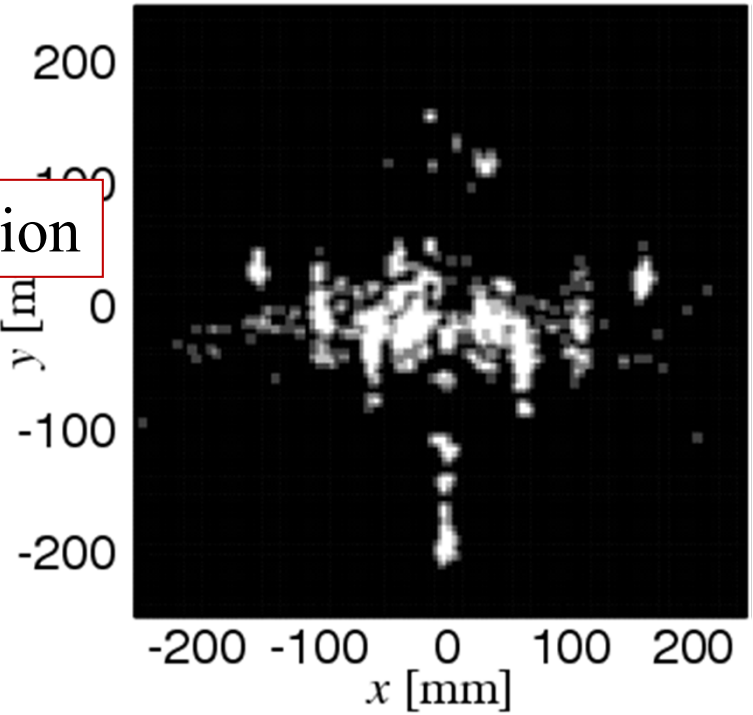
SAR image



Binarization



Binarized image



Conventional Method (Neural Network based Learning)

Neural network model : 3 layer (Input, Hidden, Output)

$\boldsymbol{x} = \lfloor x_1, \cdots, x_{N_1} \rfloor$: Binarized SAR image sequence

Neuron model of each layer

$$u_j(m) = x_j, \quad (m = 1)$$

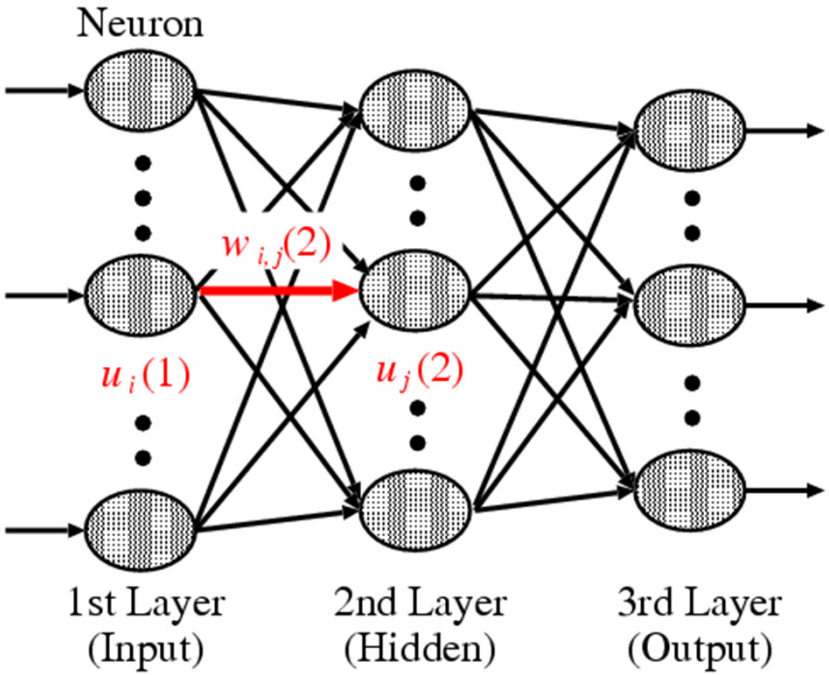
$$u_j(m) = \frac{1}{1 + \exp\left(- \sum_{i=!}^{N_{m-1}} w_{i,j}(m) u_i(m-1) \right)}$$

$$, \quad (m = 2,3)$$

$u_j(m)$: Value of j th neuron

$w_{i,j}(m)$: Weight from i th to j th neuron

3 layer neural network



Training method: Back propagation algorithm

Conventional Method (Neural Network based Classifier)

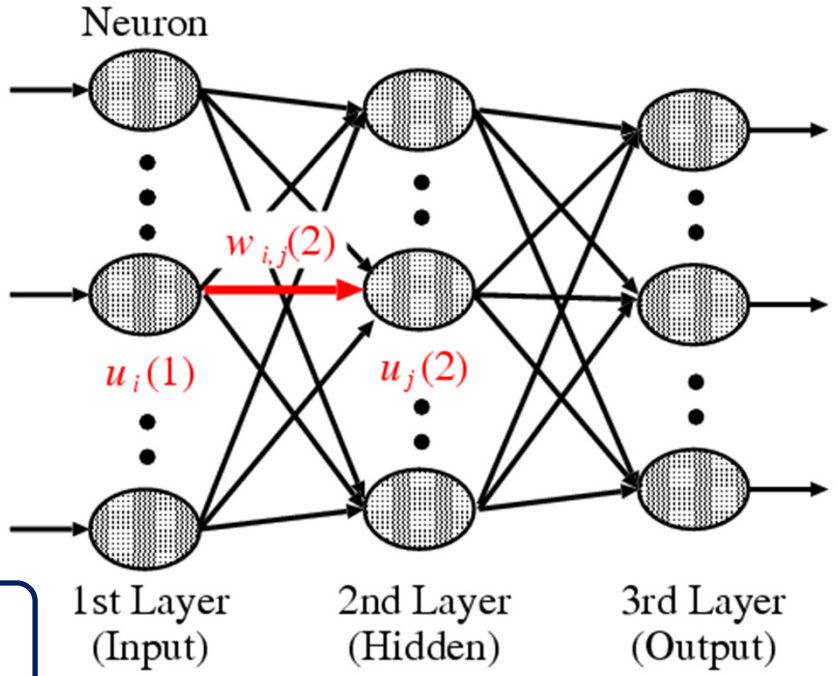
Classification Principle :
Assessing difference among neuron's values of output layer

Optimal class number is determined :

$$K_{\text{opt}}^{\text{NN}} = \arg\min_{1 \le k \le N_{\text{tr}}} \frac{\left\| \boldsymbol{u}(3) - \boldsymbol{u}_k^{\text{tr}}(3) \right\|}{\left\| \boldsymbol{u}_k^{\text{tr}}(3) \right\|}$$

$\boldsymbol{u}_k^{\text{tr}}(3)$: Output of training data

$\boldsymbol{u}(3)$: Output of test data



Problem :
Inaccuracy in lower SNR situations or other observation errors (e.g. Angle of nose)

Proposed ATR Method (SOM Training phase)

SOM (Self Organizing Map): Unsupervised neural network method

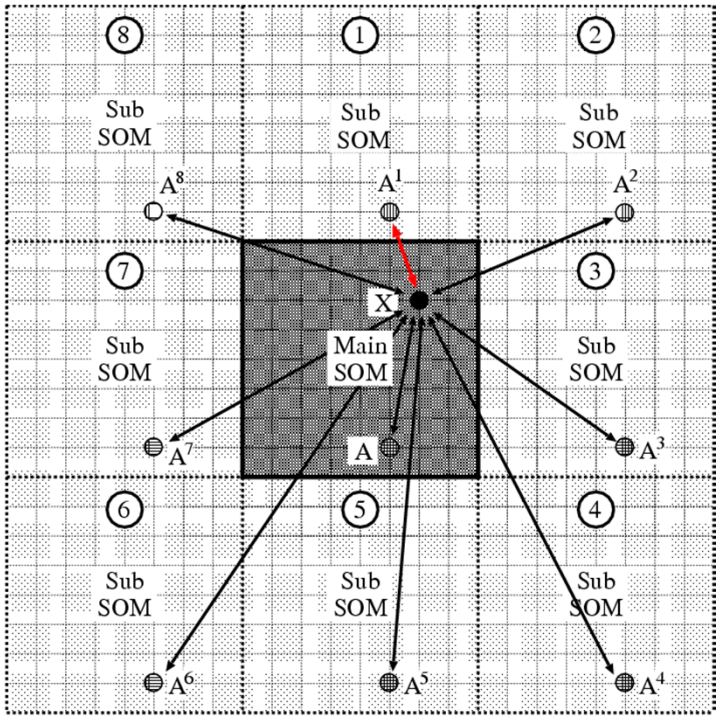
Proposed scheme : SOM classification employing training data
⇒ Supervised SOM

Other feature

1. Torus SOM
 : Periodical map structure
 ⇒ Avoiding undesired bias of node

2. BLSOM (Batch Leaning SOM)
 : Impervious to the order of training sequence

Periodical structure of SOM



Proposed ATR Method (Actual SOM training procedure)

Initial output vector on node p is defined

$$\boldsymbol{y}(\boldsymbol{p};0)=\sum_{k=1}^{N_{\mathrm{tr}}} a_k(\boldsymbol{p})\boldsymbol{x}_k^{\mathrm{tr}} \Big/ \sum_{k=1}^{N_{\mathrm{tr}}} a_k(\boldsymbol{p})$$

$\boldsymbol{p}$: Location of node

$\boldsymbol{x}_k^{\mathrm{tr}}$: Training SAR image

For k th tranning data $\boldsymbol{x}_k^{\mathrm{tr}}$, winner node $\hat{\boldsymbol{p}}_k(t)$ is determined

$$\hat{\boldsymbol{p}}_k(t)=\arg\max_{\boldsymbol{p}\in\Omega}\left\|\boldsymbol{y}(\boldsymbol{p};t)-\boldsymbol{x}_k^{\mathrm{tr}}\right\|$$

After calculating $\hat{\boldsymbol{p}}_k(t)$ for all training data,
The output of each node is updated by :

$$\boldsymbol{y}(\boldsymbol{p};t+1)=\boldsymbol{y}(\boldsymbol{p};t)+\frac{\sum_{k=1}^{N_{\mathrm{tr}}} h(\hat{\boldsymbol{p}}_k(t),\boldsymbol{p})\left(\boldsymbol{x}_k^{\mathrm{tr}}-\boldsymbol{y}(\boldsymbol{p};t)\right)}{\sum_{k=1}^{N_{\mathrm{tr}}} h(\hat{\boldsymbol{p}}_k(t),\boldsymbol{p})}$$

$$h(\hat{\boldsymbol{p}}_k(t),\boldsymbol{p})=\beta(t)\exp\left(\frac{\left\|\hat{\boldsymbol{p}}_k(t)-\boldsymbol{p}\right\|}{2\sigma(t)^2}\right)$$

$\beta(t), \sigma(t)$: Monotonically decreasing for t

Proposed ATR Method (Classification Phase)

Classification Principle :
Assessing value of integral of U-matrix field from training node

Winner node for test data $\boldsymbol{x}$

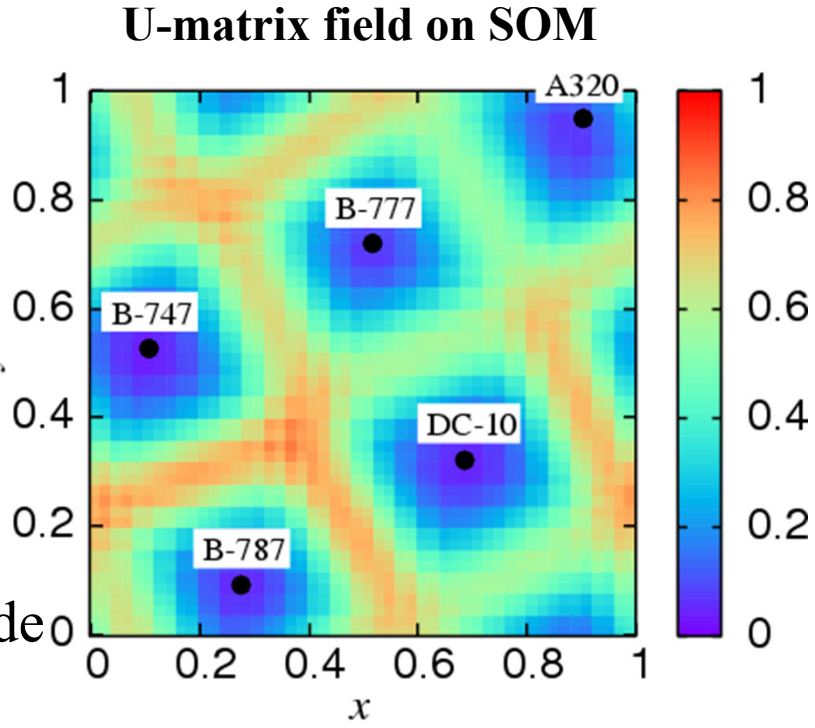
$$\hat{\boldsymbol{p}}(\boldsymbol{x}) = \arg\min_{\boldsymbol{p}\in\Omega} \left\| \boldsymbol{y}(\boldsymbol{p}; T_{\text{som}}) - \boldsymbol{x} \right\|$$

Optimal class number is determined :

$$K_{\text{opt}}^{\text{som}} = \arg\min_{1\le k\le N_{\text{tr}}} \left\{ \min_{C(k,\boldsymbol{x})} \int_{C(k,\boldsymbol{x})} U(\boldsymbol{p})\, \mathrm{d}s \right\}$$

$U(\boldsymbol{p})$: U-matrix potential at node $\boldsymbol{p}$

$C(k,x)$: Possible path from k th training node to winner node $\hat{\boldsymbol{p}}(\boldsymbol{x})$



Proposed ATR Method (Classification Phase: U-matrix metric)

Classification Principle :
Assessing value of integral of U-matrix field from training node

Winner node for test data $\boldsymbol{x}$

$$\hat{\boldsymbol{p}}(\boldsymbol{x}) = \arg\min_{\boldsymbol{p}\in\Omega} \left\| \boldsymbol{y}\left(\boldsymbol{p}; T_{\text{som}}\right) - \boldsymbol{x} \right\|$$

Optimal class number is determined :

$$K_{\text{opt}}^{\text{som}} = \arg\min_{1\le k\le N_{\text{tr}}} \left\{ \min_{C(k,\boldsymbol{x})} \int_{C(k,\boldsymbol{x})} U(\boldsymbol{p})\, \mathrm{d}s \right\}$$

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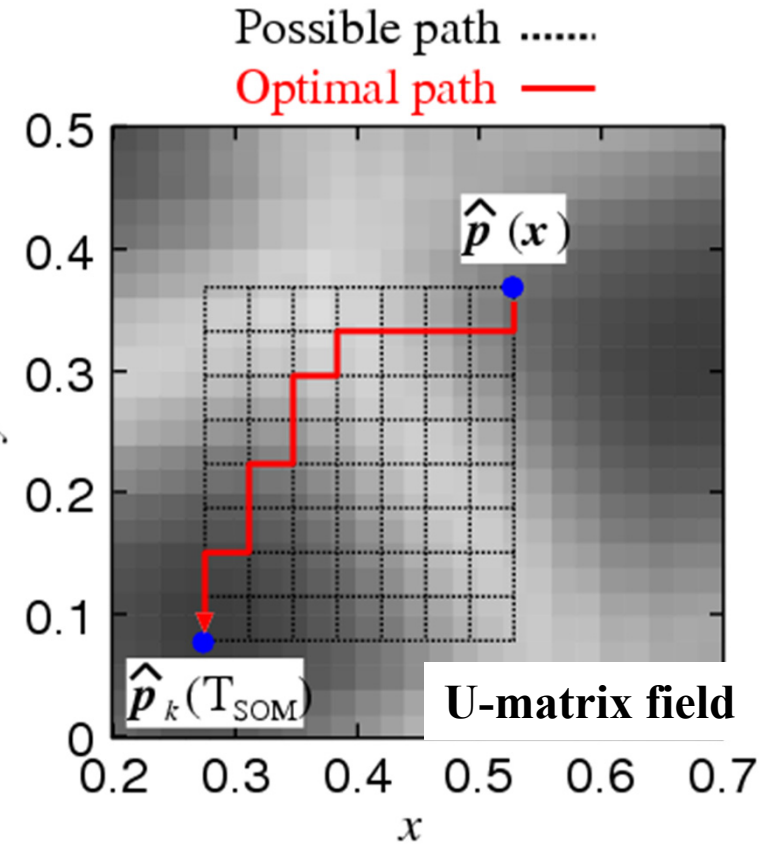
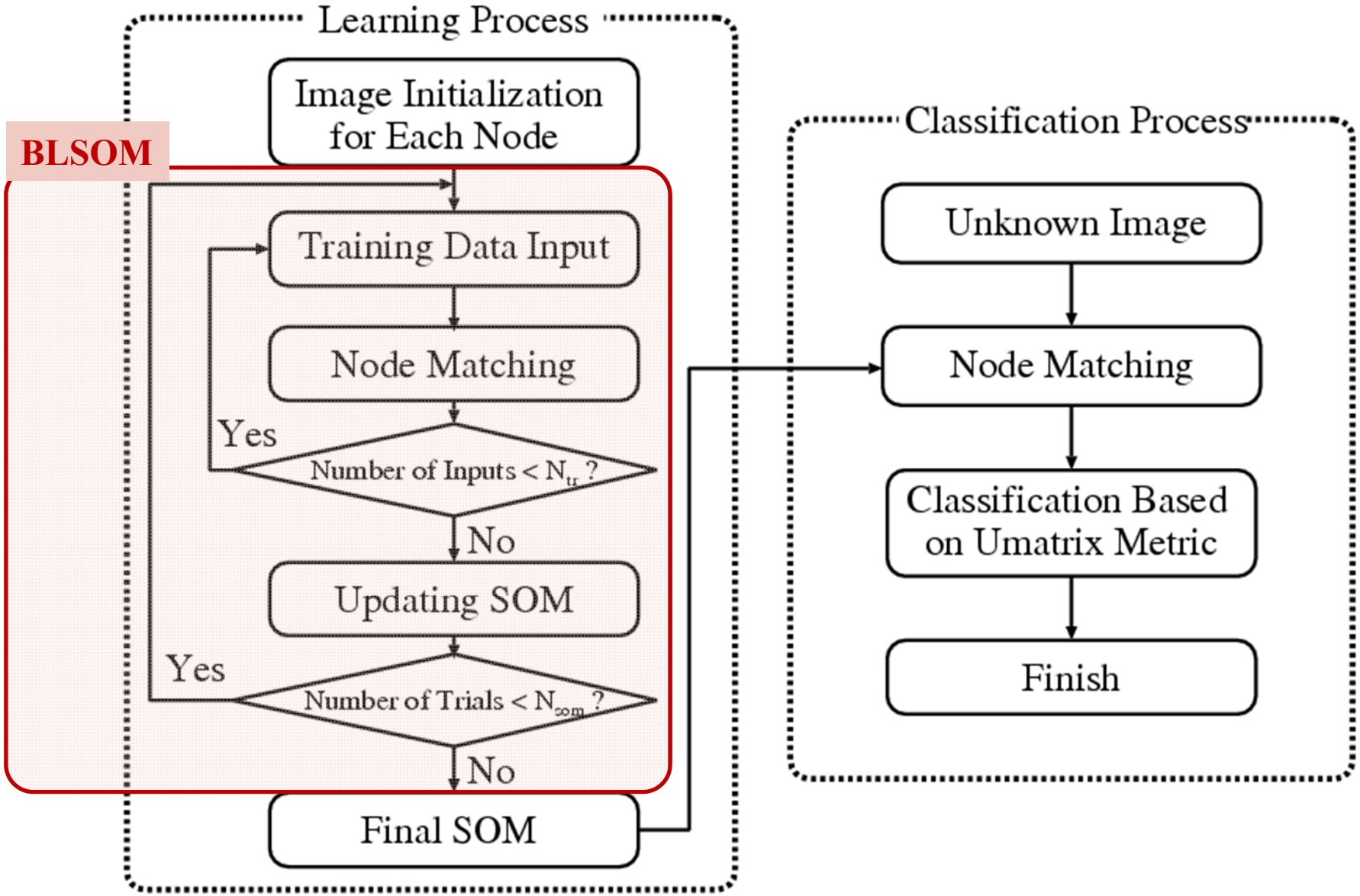


Procedure of Proposed Method

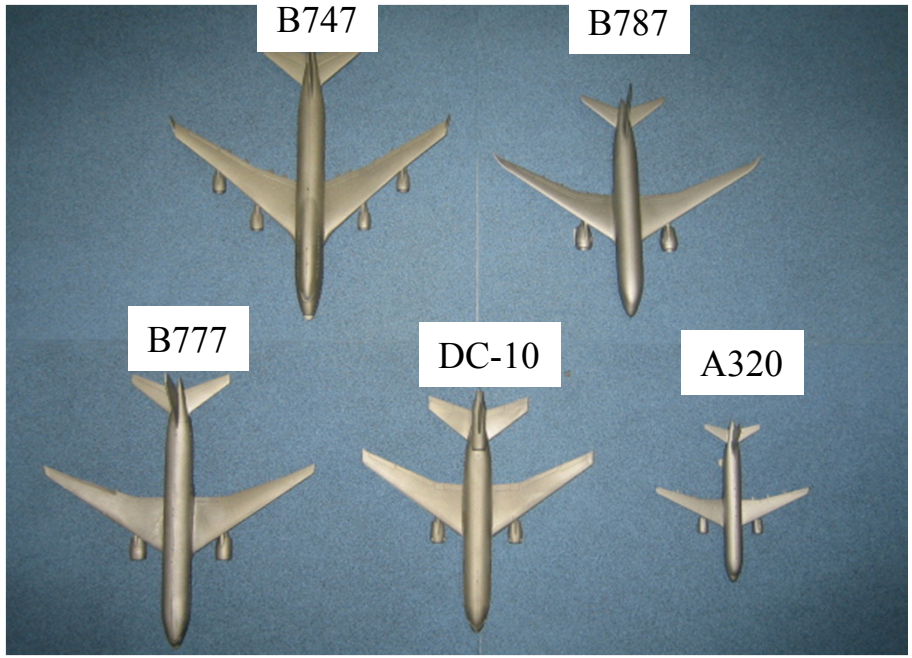


Experimental Validation

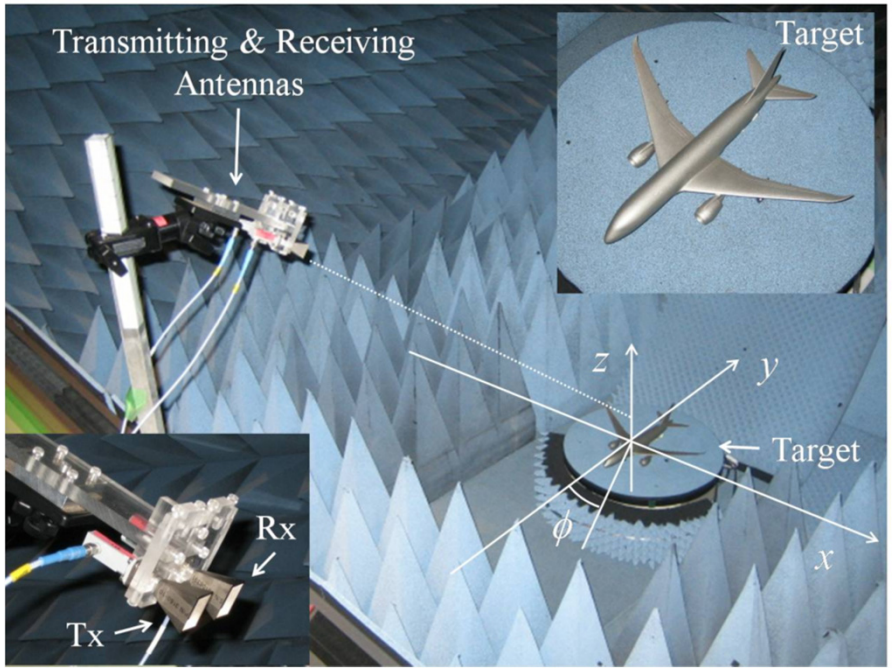
Experimental setup :1/200 downscaled model of X-band radar except for center frequency

- Horn antennas (Beamwidth : 27 deg)
- Slant range resolution : 9.375 mm
- Off-nadir angle : 54.7 degree
- Frequency range: 24GHz – 40GHz
- Aperture Length : 1600 mm
- Tx and Rx Separation : 48 mm

Optical image for 5 civilian airplanes



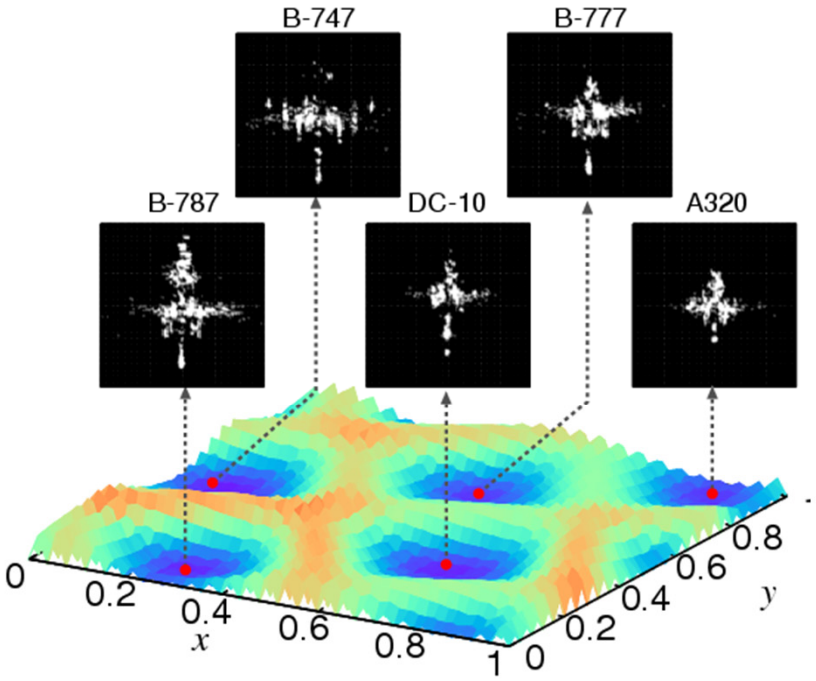
Observation scene in experiment



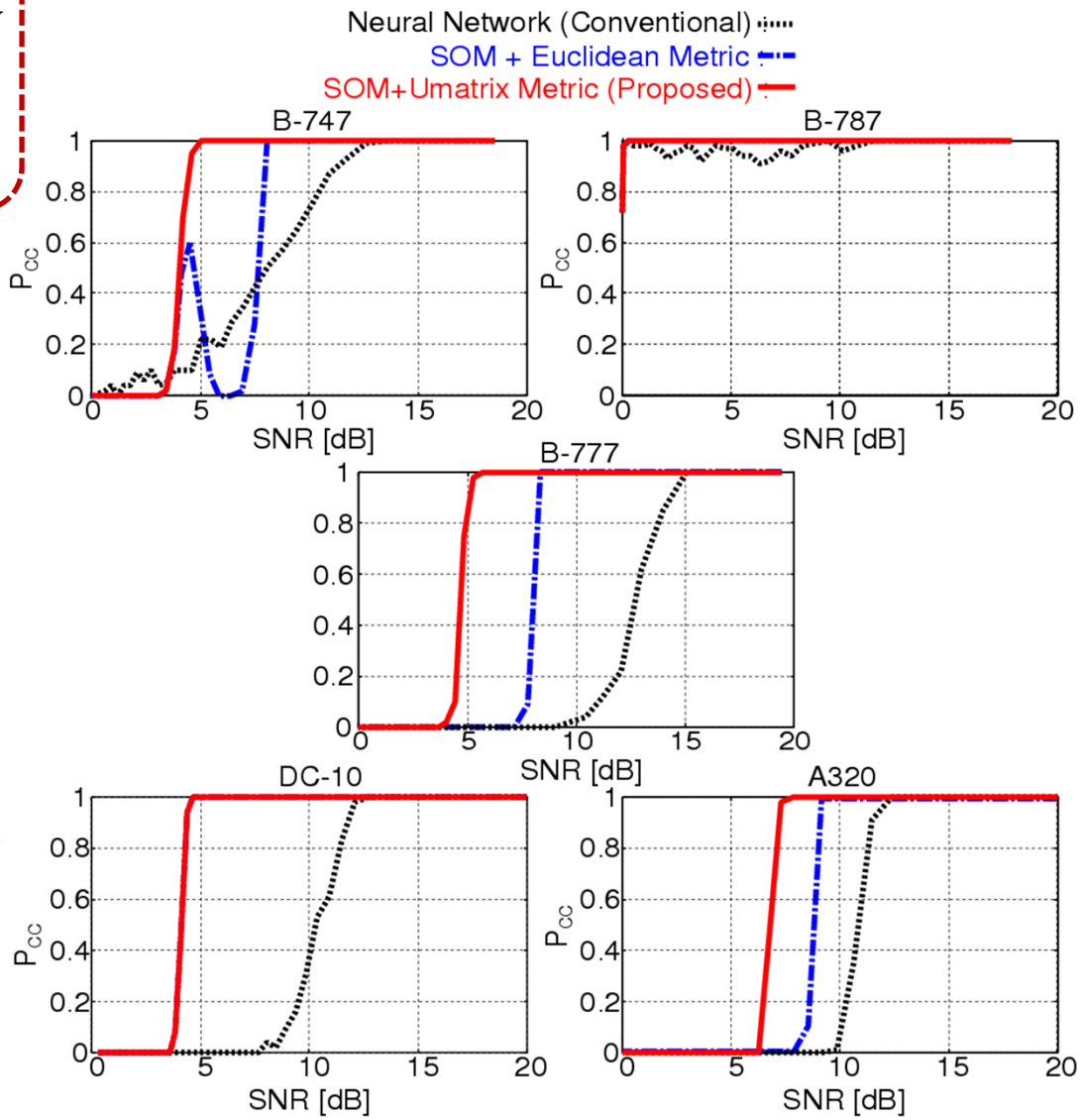
Evaluation in Noisy Situation

Gaussian noises are numerically added to SAR images for contaminated image generation

U-matrix potential distribution

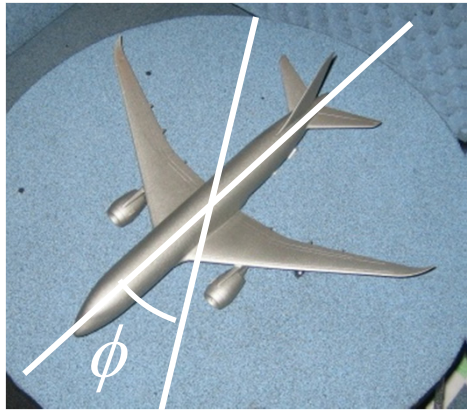


Correct classification probability

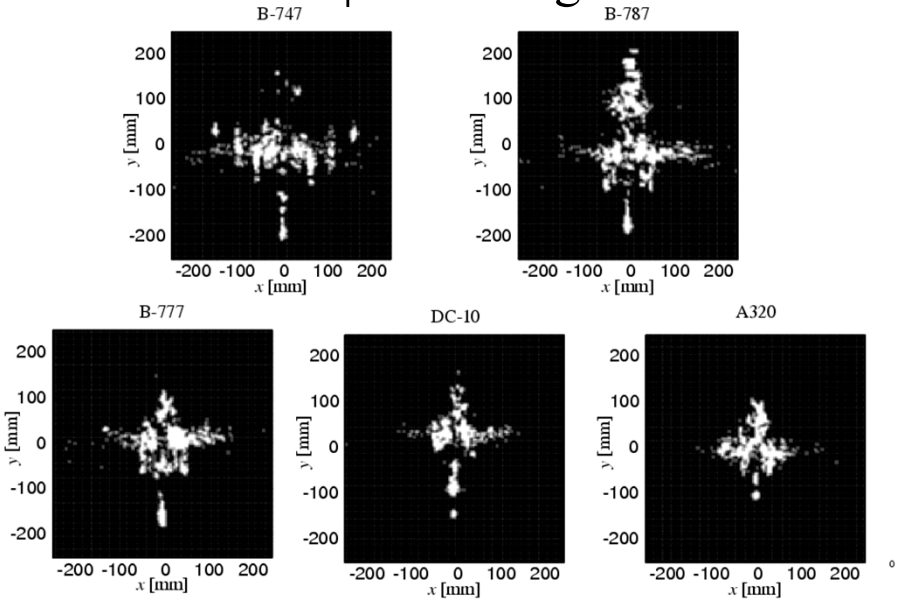


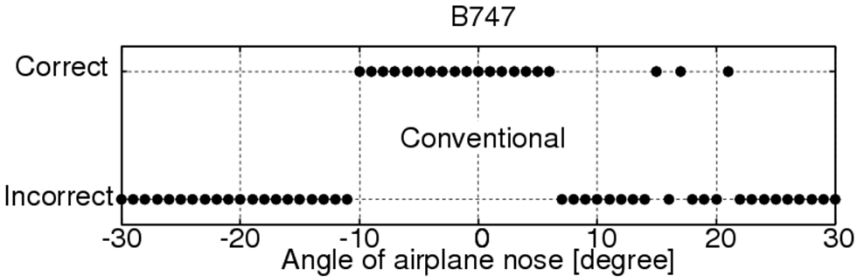
Robustness to Observation Angle Errors

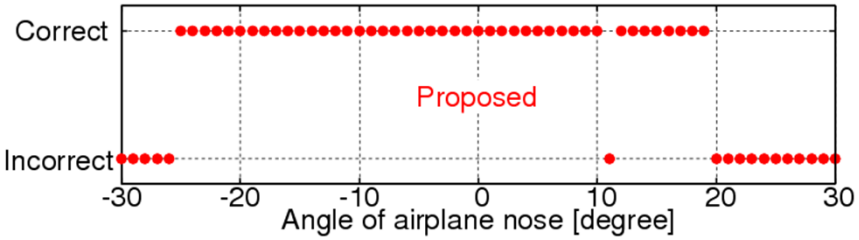
Angle observation error : φ

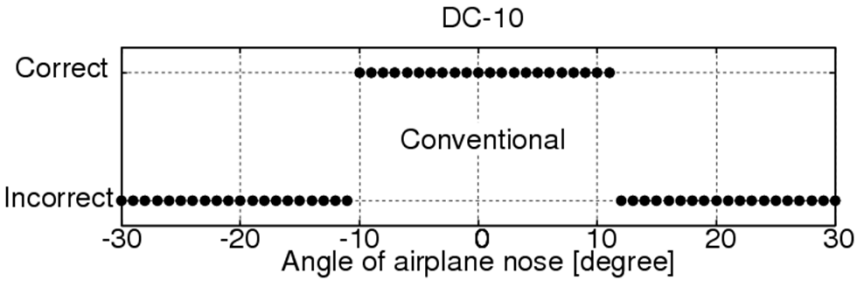


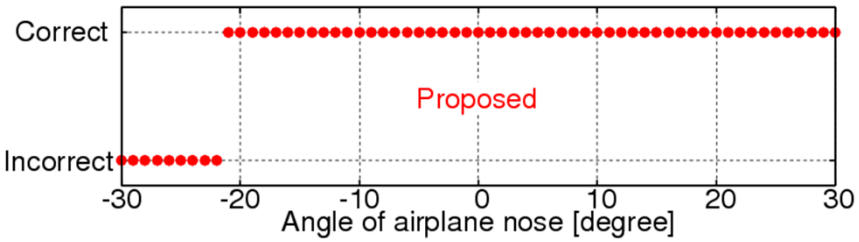
φ = 0 deg











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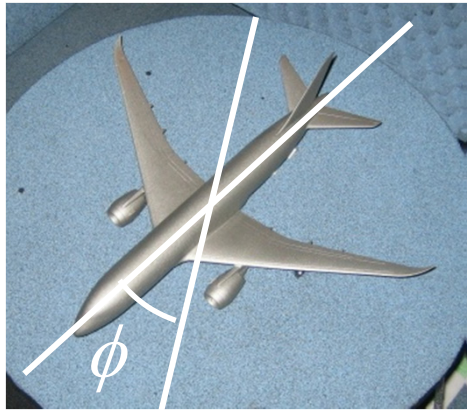
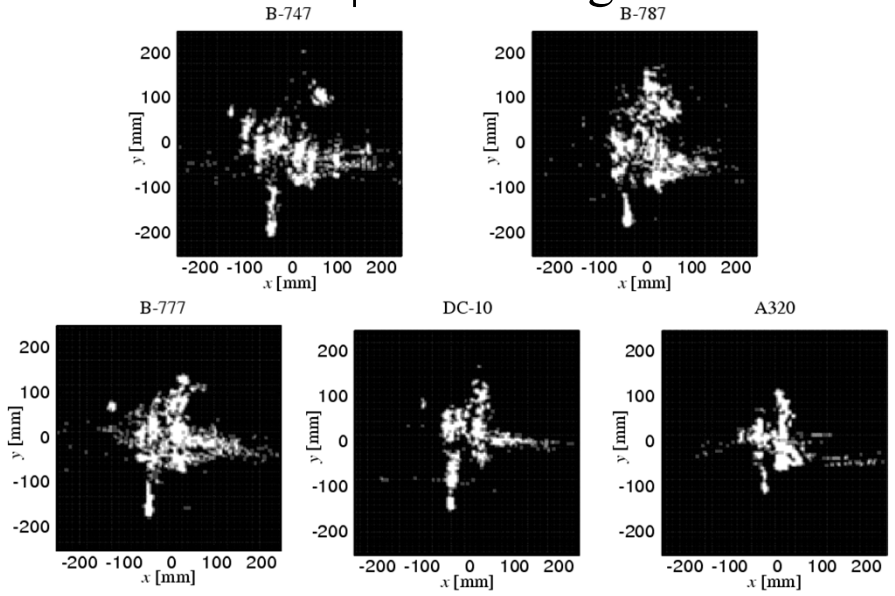
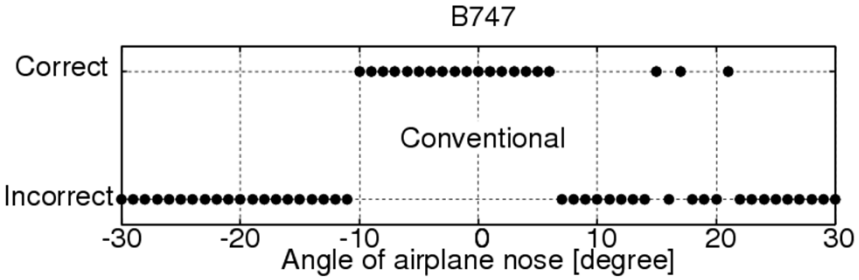
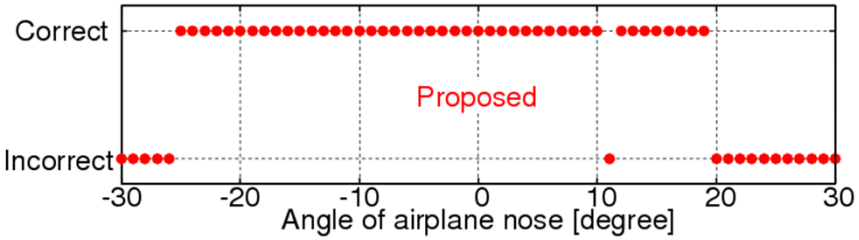
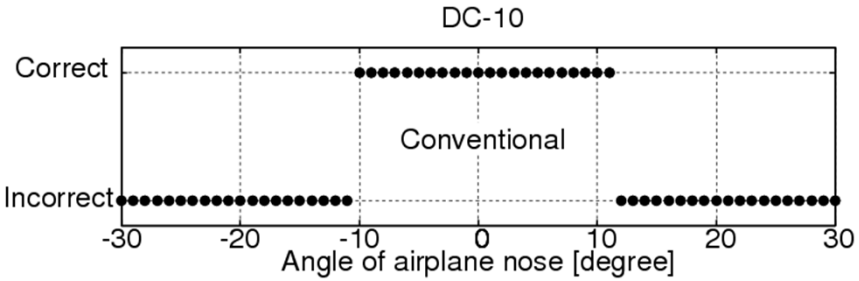


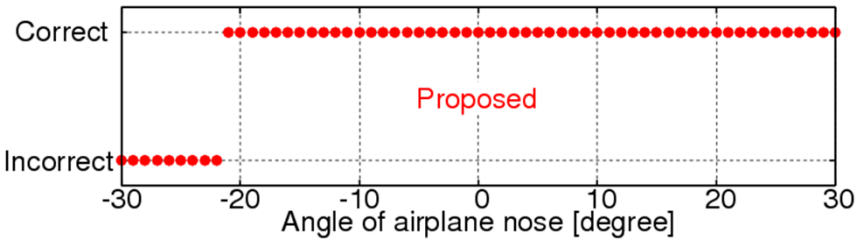
φ = 15 deg











Conclusion

- Accurate ATR method based on Supervised SOM has been proposed

- Proposed method
  1. Supervised SOM for ATR classification issue
  2. New classification metric by using U-matrix metric

- Experimental validation :
  - Correct classification even in under SNR=10 dB
  - Robust feature for observation angle errors

Future work

- More accurate method exploiting complex value of SAR image