博士論文 (要約)

PolSAR Land Classification System Based on Unsupervised Adaptive Polarization Scattering Signal Processing Using Quaternion Neural Networks

(四元数ニューラルネットワークによる偏波散乱情報の教師なし適応処理に基づくPolSAR地表分類システム)

平成30年06月01日提出
指導教員　廣瀬 明　教授

東京大学大学院工学系研究科
電気系工学専攻
37 – 167297
金 炫秀

PolSAR is an active sensor that observes target by transmitting polarization-controlled microwave and receiving their scattered wave in a polarization-sensitive manner. Since it can observe the target irrespective of the weather condition throughout day and night, various studies have been carried out to utilize PolSAR data for resource management [1–5], environmental protection [6–10] and disaster measures [11–13]. To realize these, accurate land classification using PolSAR is one of the research goals, which has been receiving a lot of attention.

Since 1990s, a number of PolSAR land classification systems have been reported. The target decomposition methods [14–20], which have been studied actively from the beginning in this field, show a high potential of PolSAR land classification. It has become possible to classify the PolSAR-observed areas into several specific categories such as farm, forest, lake and so on, combined with statistical modeling [21–24]. Machine-learning-based classifiers such as K-means [25–27], support vector machine (SVM) [28, 29], fuzzy logic [30–32], neural networks [33–38], have greatly enhanced the accuracy of the PolSAR land classification.

The target decomposition selects the feature information necessary for land classification from PolSAR data based on the assumption that a unique combination of scattering mechanisms exists for each land category. Model-based decomposition can be introduced as a typical technique of the target decomposition. The three-component decomposition [16] proposed by Freeman and Durden in 1998 represents feature information based on the combination of three scattering mechanisms by deciding that the land surface can be represented by a combination of three simple scattering models, namely, single-bounce scattering, double-bounce scattering and volume scattering. The four-component decomposition [17] proposed by Yamaguchi et al. in 2005 can find an appropriate combination of feature information which is necessary for the classification of special structure by adding helix scattering to the three component decomposition. Various other additional methods have also been proposed such as the deorientation method [20] and the cross scattering model [18, 19] to suppress unevenness in the direction of buildings.

However, since the above methods extract feature information based on a few scattering mechanisms selected by humans, it is sometimes necessary to define new scattering mechanisms that correspond to the change or addition of classification objects. Though the adaptive-classifier having high performance is employed, a high classification performance can not be obtained since the conventional systems are based on features which are not able to express the actual land surface clearly. There would be limitations in these methods in the near future to meet the requirement of various land categories that human beings perceive.

The author aims to achieve the following two goals through this research. First, the author aims to overcome the limitation of the classification targets of the conventional PolSAR land classification system. It can be solved by fully utilizing the polarization scattering information of PolSAR data with various

directional Poincare parameters. However, the algorithms for removing unnecessary noise from the Poincare parameters and the land classification methods based on the Poincare parameter are still not established. The author proposes several unsupervised adaptive polarization scattering signal processing methods using quaternion neural networks and realize an unsupervised PolSAR land classification system based on the proposed methods. Second, the author aims to discover new land classes that are not considered classifiable by using PolSAR data. The conventional PolSAR land classification systems can classify only the several simple land classes such as water, forest, and town, so its application range is insufficient compared to the economic burden required for the development and operation of the PolSAR system. Discovering new land classes that can be classified using PolSAR data through this research, will significantly enhance the economic value of the PolSAR system by expanding the scope of data utilization hugely. As a result, by proposing several unsupervised adaptive polarization scattering signal processing methods using quaternion neural networks, we succeed in realization of the unsupervised PolSAR land classification system which discovers new land classes without pre-definition or learning by human beings. The research results obtained in this doctoral work can be summarized as follows.

In Chapter 2, we propose an unsupervised PolSAR land classification system based on quaternion auto-encoder and quaternion SOM. The proposed system not only distinguishes the PolSAR data without human-predefined land categories, but also labels respective groups by an additional labeling process so that human beings can understand the unsupervised classification results. We confirm that the quaternion auto-encoder is effective in extracting feature vectors suitable for land classification. It enables the proposed system to classify the PolSAR data obtained for the target region accurately and finely. Furthermore, we succeed in discovering more detailed land categories such as furrowed areas, factory areas, and so on, by classifying the ALOS data obtained for Fujisusono region with quaternion SOM having 10×10 neuron array.

In Chapter 3, we propose hierarchical polarization feature generation with self-organizing codebook to realize unsupervised land classification for high-resolution PolSAR data. Since the respective pixels of high-resolution PolSAR data contain the detailed polarization scattering properties obtained from the local land areas, it is hard to realize the accurate land classification based on single pixels. The proposed system generates the self-organizing codebook representing the typical respective pixel signals of high-resolution PolSAR data by using the combination of the quaternion auto-encoder and quaternion SOM. Then, the PolSAR data is scanned by the patch window to generate high-level feature vectors by constructing the winner histogram of the self-organizing codebook. In the experimental results, we confirm that proposed system performs high-resolution PolSAR land classification without any predefinition or training by human beings. Furthermore, we succeed in discovery of the new land sub-classes which can be discovered only in high-resolution PolSAR data. For

example, two kinds of farm areas are classified successfully, and buildings are classified into the center parts and the wall parts in detail. The proposed system makes it possible to fully utilize the detailed polarization scattering properties contained in respective pixels for land classification even if the resolution of PolSAR data keeps being enhanced continuously. This leads to the discoveries of new land categories that can only be found with high-resolution PolSAR data.

In Chapter 4, we optimize the hierarchical polarization feature generation, which has been proposed in Chapter 3, by applying the concept of population coding. Since the method proposed in Chapter 3 is based on the concept of sparse coding, we do not obtain high performance in land classification unless we prepare the suitable self-organizing codebook for the respective observation regions. However, the optimized method based on the concept of population coding shows the stable land classification performance at all times without having to generate the optimal self-organizing codebook. It enables us to utilize the proposed hierarchical PolSAR land classification system flexibly for classification of various observed regions.

In Chapter 5, we report the experimental analysis results of the pixel variation existing in actual PolSAR data of various resolution. Until now, it has been believed that the main cause of pixel variation in PolSAR data is a non-uniform distribution of the local scatterers in the land surface. For this reason, even though the PolSAR data of decimeter-resolution could be observed, it was being considered that the data resolution should be reduced from 10m to 20m based on the real-space-distance to obtain the polarization scattering information suitable for the land classification. However, from the experimental results, we confirm that a non-uniform distribution of the local scatterers in the land surface is not the main cause of pixel variation. And it means that there is no need to lower the resolution of high-resolution PolSAR data in the same level of pixel spacing as low-resolution PolSAR data to apply for land classification. Our experimental results show that the polarization scattering information of the high-resolution data is available for utilizatoin for the land classification fully.

The above research results enable us to fully utilize the detailed polarization scattering properties contained in respective pixels for land classification even if the resolution of PolSAR data keeps getting enhanced continuously. Besides, we can realize the stable classification performance regardless of the type of the observation region. In the future, if the resolution of PolSAR data increases much more, we expect even the classification of the buildings based on their detailed shapes by using the proposed method. Expansion of the classification target that can be classified using PolSAR data, will significantly enhance the economic value of the PolSAR system by expanding the scope of data utilization hugely.

Reference

[1] Henning Skriver. Crop classification by multitemporal C-and L-band single-and dual-polarization and fully polarimetric SAR. *IEEE Transactions on Geoscience and Remote Sensing*, 50(6):2138–2149, 2012.

[2] Bin Zou, Chenyi Wang, Chenyi Wang, and Lamei Zhang. Coastline detection based on polarimetric characteristics and mathematical morphology using PolSAR images. *in IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, pages 4562–4565, 2017.

[3] lingli Zhao, Jie Yang, Pingxiang Li, Jinqi Zhao, Lei Shi, and Zhaoxiang Yuan. Detection of the lodged area of wheat by the use of RADARSAT-2 polarimetric SAR imagery. *in IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, pages 4366–4369, 2017.

[4] Davide Pirrone, Shaunak De, Avik Bhattacharya, Lorenzo Bruzzone, and Francesca Bovolo. Unsupervised change detection in built-up areas by multi-temporal polarimetric SAR images. *in IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, pages 4554–4557, 2017.

[5] Tao Zhang, Zhen Yang, and Huilin Xiong. PolSAR ship detection based on the polarimetric covariance difference matrix. *in IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, pages 3348–3359, 2017.

[6] Guandong Chen, Guangmin Sun, and Yuanzhi Zhang. Polarimetric SAR oil spill detection based on deep networks. *in IEEE International Conference on Imaging Systems and Techniques (IST)*, pages 1–5, 2017.

[7] Christian N. Koyama, Manabu Watanabe, Masato Hayashi, and Masanobu Shimada. The effect of precipitation and soil moisture variations on (partial) polarimetric L-band SAR backscatter in tropical forest regions. *in IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, pages 2450–2453, 2017.

[8] Oliver Boisot, Sebastien Angelliaume, and Charles-Antoine Guerin. Introduction to oil quantification on sea surface from microwaves polarimetric SAR measurements. *in IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, pages 4437–4440, 2017.

[9] Macro Lavalle. A new automated algorithm for detecting forest disturbances with the dual-polarimetric SAR alpha angle. *in IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, pages 5299–5302, 2017.

[10] Georg Fischer, Giuseppe Parrella, Konstantinos P. Papathanassiou, and Irena Hajnsek. Sensitivity of polarimetric SAR interferometry data to different vertical subsurface structures of the Greenland ice sheet. *in IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, pages 3581–3584, 2017.

[11] Motoyuki Sato, Si-Wei Chen, and Makoto Satake. Polarimetric SAR analysis of tsunami damage following the March 11, 2011 East Japan earthquake. *Proceedings of the IEEE*, 100(10):2861–2875, 2012.

[12] Si-Wei Chen and Motoyuki Sato. Tsunami damage investigation of built-up areas using multitemporal spaceborne full polarimetric SAR images. *IEEE Transactions on Geoscience and Remote Sensing*, 51(4):1985–1997, 2013.

[13] Si-Wei Chen, Xue-Song Wang, and Motoyuki Sato. Urban damage level mapping based on scattering mechanism investigation using fully polarimetric SAR data for the 3.11 East Japan earthquake. *IEEE Transactions on Geoscience and Remote Sensing*, 54(12):6919–6929, 2016.

[14] Ernst Krogager. Decomposition of the radar target scattering matrix with application to high resolution target imaging. *in IEEE National Telesystems Conference Proceedings (NTC)*, pages 77–82, 1991.

[15] Shane R Cloude and Eric Pottier. An entropy based classification scheme for land applications of polarimetric SAR. *IEEE Transactions on Geoscience and Remote Sensing*, 35(1):68–78, 1997.

[16] Anthony Freeman and Stephen L Durden. A three-component scattering model for polarimetric SAR data. *IEEE Transactions on Geoscience and Remote Sensing*, 36(3):963–973, 1998.

[17] Yoshio Yamaguchi, Toshifumi Moriyama, Motoi Ishido, and Hiroyoshi Yamada. Four-component scattering model for polarimetric SAR image decomposition. *IEEE Transactions on Geoscience and Remote Sensing*, 43(8):1699–1706, 2005.

[18] Toshifumi Moriyama, Seiho Uratsuka, Toshihiko Umehara, Hideo Maeno, Makoto Satake, Akitsugu Nadai, and Kazuki Nakamura. Polarimetric SAR image analysis using model fit for urban structures. *IEICE Transactions on Communications*, 88(3):1234–1243, 2005.

[19] Lamei Zhang, Bin Zou, Hongjun Cai, and Ye Zhang. Multiple-component scattering model for polarimetric SAR image decomposition. *IEEE Geoscience and Remote Sensing Letters*, 5(4):603–607, 2008.

[20] Yoshio Yamaguchi, Akinobu Sato, Wolfgang-Martin Boerner, Ryoichi Sato, and Hiroyoshi Yamada. Four-component scattering power decomposition with rotation of coherency matrix. *IEEE Transactions on Geoscience and Remote Sensing*, 49(6):2251–2258, 2011.

[21] JS Lee, DL Schuler, RH Lang, and KJ Ranson. K-distribution for multilook processed polarimetric SAR imagery. *in IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, 4:2179–2181, 1994.

[22] Michelle M Horta, Nelson DA Mascarenhas, Alejandro C Frery, and Alexandre LM Levada. Clustering of fully polarimetric SAR data using finite G_p^0 mixture model and SEM algorithm. *in IEEE International Conference on Systems, Signals and Image Processing (IWSSIP)*, pages 81–84, 2008.

[23] Lionel Bombrun, Gabriel Vasile, Michel Gay, and Felix Totir. Hierarchical segmentation of polarimetric SAR images using heterogeneous clutter models. *IEEE Transactions on Geoscience and Remote Sensing*, 49(2):726–737, 2011.

[24] Vahid Akbari, Anthony P Doulgeris, Gabriele Moser, Torbjørn Eltoft, Stian N Anfinsen, and Sebastiano B Serpico. A textural–contextual model for unsupervised segmentation of multipolarization synthetic aperture radar images. *IEEE Transactions on Geoscience and Remote Sensing*, 51(4):2442–2453, 2013.

[25] Robert Amelard, Alexander Wong, and David A Clausi. Unsupervised classification of agricultural land cover using polarimetric synthetic aperture radar via a sparse texture dictionary model. *in IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, pages 4383–4386, 2013.

[26] Deliang Xiang, Tao Tang, Yifang Ban, Yi Su, and Gangyao Kuang. Unsupervised polarimetric SAR urban area classification based on model-based decomposition with cross scattering. *ISPRS Journal of Photogrammetry and Remote Sensing*, 116:86–100, 2016.

[27] Rogério Galante Negri, Wagner Barreto da Silva, and Tatiana Sussel Gonçalves Mendes. K-means algorithm based on stochastic distances for polarimetric synthetic aperture radar image classification. *Journal of Applied Remote Sensing*, 10(4):045005–045005, 2016.

[28] S Fukuda and H Hirosawa. Support vector machine classification of land cover: Application to polarimetric SAR data. *in IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, 1:187–189, 2001.

[29] Cédric Lardeux, Pierre-Louis Frison, Céline Tison, Jean-Claude Souyris, Benoît Stoll, Bénédicte Fruneau, and Jean-Paul Rudant. Support vector machine for multifrequency SAR polarimetric data classification. *IEEE Transactions on Geoscience and Remote Sensing*, 47(12):4143–4152, 2009.

[30] L Du and JS Lee. Fuzzy classification of earth terrain covers using complex polarimetric SAR data. *International Journal of Remote Sensing*, 17(4):809–826, 1996.

[31] Chia-Tang Chen, Kun-Shan Chen, and Jong-Sen Lee. The use of fully polarimetric information for the fuzzy neural classification of SAR images. *IEEE Transactions on Geoscience and Remote Sensing*, 41(9):2089–2100, 2003.

[32] Paul R Kersten, Jong-Sen Lee, and Thomas L Ainsworth. Unsupervised classification of polarimetric synthetic aperture radar images using fuzzy clustering and EM clustering. *IEEE Transactions on Geoscience and Remote Sensing*, 43(3):519–527, 2005.

[33] Fang Shang and Akira Hirose. Quaternion neural-network-based PolSAR land classification in Poincare-sphere-parameter space. *IEEE Transactions on Geoscience and Remote Sensing*, 52(9):5693–5703, 2014.

[34] Qi Lv, Yong Dou, Xin Niu, Jiaqing Xu, Jinbo Xu, and Fei Xia. Urban land use and land cover classification using remotely sensed SAR data through deep belief networks. *Journal of Sensors*, 2015, 2015.

[35] Yanhe Guo, Shuang Wang, Chenqiong Gao, Danrong Shi, Donghui Zhang, and Biao Hou. Wishart RBM based DBN for polarimetric synthetic radar data classification. *in IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, pages 1841–1844, 2015.

[36] Bo Chen, Shuang Wang, Licheng Jiao, Rustam Stolkin, and Hongying Liu. A three-component fisher-based feature weighting method for supervised PolSAR image classification. *IEEE Geoscience and Remote Sensing Letters*, 12(4):731–735, 2015.

[37] Yuto Takizawa, Fang Shang, and Akira Hirose. Adaptive land classification and new class generation by unsupervised double-stage learning in Poincare sphere space for polarimetric synthetic aperture radars. *Neurocomputing*, 2017.

[38] Hyunsoo Kim and Akira Hirose. Unsupervised fine land classification using quaternion autoencoder-based polarization feature extraction and self-organizing mapping. *IEEE Transactions on Geoscience and Remote Sensing*, 56(3):1839–1851, 2018.

Publications and Awards

Publications in the doctoral course

Journals

1. H. Kim and A. Hirose. Experimental analysis of pixel variation properties in PolSAR data of various resolution. *IEEE Transactions on Geoscience and Remote Sensing*, In preparation.

2. H. Kim and A. Hirose. Population coding for optimization of unsupervised hierarchical quaternion neural network using self-organizing codebook. *IEEE Transactions on Neural Network Learning System*, In preparation.

3. H. Kim and A. Hirose. Unsupervised hierarchical land classification using self-organizing feature codebook for decimeter-resolution PolSAR. *IEEE Transactions on Geoscience and Remote Sensing*, In review.

4. H. Kim and A. Hirose. Quaternion neural-network-based PolSAR land classification in Poincare-sphere-parameter space. *IEEE Transactions on Geoscience and Remote Sensing*, vol. 56(3), pp. 1839-1851, 2018.

5. H. Kim and A. Hirose. 四元数オートエンコーダと四元数 SOM の連携による柔軟な偏波散乱信号処理: 偏波合成開口レーダ地表分類での利用. 日本知能情報ファジィ学会誌 *(*知能と情報*)*, vol. 3(2), pp. 89-97, 2018, Japan (招待論文).

International Conferences

1. H. Kim and A. Hirose. Codebook-based hierarchical polarization feature for unsupervised fine land classi-fication using high-resolution PolSAR data. *Int' l Geoscience and Remote Sensing Symposium 2018, Spain*, to be presented.

2. H. Kim and A. Hirose. Polarization feature extraction using quaternion neural networks for flexible unsu-pervised PolSAR land classification. *Int'*

l Geoscience and Remote Sensing Symposium 2018, Spain, to be presented.

3. H. Kim and A. Hirose. Unsupervised PolSAR land classification based on quaternion neural networks. *in Joint PI Meeting of Global Environment Observation Mission FY2017 of JAXA, Japan.*

Domestic Conferences

1. H. Kim and A. Hirose. 教師なし PolSAR 地表分類のための自己組織化コードブックを用いた階層的四元数ニューラルネットワーク. 電子情報通信学会 ニューロコンピューティング研究会 *(IEICE-NC)*, vol. IEICE-117 (508), pp. 121-126, Mar. 2018, Japan.

2. H. Kim and A. Hirose. 階層的な偏波特徴ベクトルによる高分解能 PolSAR データの教師なし地表分類. 電子情報通信学会 総合大会, Mar. 2018, Japan.

3. H. Kim and A. Hirose. 四元数ニューラルネットワークをベースにした柔軟な教師なし PolSAR 地表分類システム. 電子情報通信学会 電磁界理論研究会 *(IEICE-EMT)*, vol. IEICE-117 (289), pp. 37-42, Nov. 2017, Japan.

4. H. Kim and A. Hirose. Unsupervised adaptive PolSAR land classification system using quaternion neural networks. 電子情報通信学会 宇宙・航行エレクトロニクス研究会 *(IEICE-SANE)*, vol. IEICE-117 (222), pp. 73-78, Oct. 2017, Japan.

5. H. Kim and A. Hirose. Quaternion Auto-Encoder と Quaternion SOM の連携による教師なし PolSAR 地表分類. 日本神経回路学会 総合大会, Sep. 2017, Japan.

6. H. Kim and A. Hirose. 教師なし PolSAR 地表分類のための Quaternion Auto-Encoder による偏波特徴抽出と自己組織化マッピング. 電子情報通信学会 総合大会, Sep. 2017, Japan.

7. H. Kim and A. Hirose. Unsupervised adaptive land classification using quaternion neural network. *in JAXA Pi-SAR-L2 Workshop*, Feb. 2017, Japan.

Others

1. H. Kim and A. Hirose. Flexible unsupervised PolSAR land classification system based on quaternion neural networks. *n Meeting of Joint Research with IIT Roorkee*, Feb. 2017, India.

2. H. Kim and A. Hirose. Polarimetric synthetic-aperture-radar land classification based on quaternion au-to-encoder and quaternion self-organizing map. *in Nation-wide Cooperative Research Project: information-representation optimiza-tion in high-dimensional neural networks*, Dec. 2017, Japan.

Awards

1. 電子情報通信学会 2017 年ソサイエティ大会: エレクトロニクスソサイエティ学生奨励賞.

Publications unrelated to the doctoral work

Journals

1. H. Kim and Y. Choi. A camber monitoring system of RM zone based on direction-selective edge-detection algorithm. *Journal of Institute of Control, Robots and Systems (ICROS)*, ol. 21(8), pp. 713?717, 2015, South Korea.

International Conferences

1. H. Kim and T. Shibata. irectional-edge-space processing for multiple-resolution image perception. *n IEEE World Automation Congress (WAC) 2010, Japan.*

Domestic Conferences

1. H. Kim and Y. Choi. Threading monitoring system on RM zone based on camera image. *in ICROS* 総合大会, May 2015, South Korea.

2. H. Kim and J. Lee, Tracking system using RFID for vertical reducing furnace on Mg smelting process. *in ICROS* 総合大会, May 2014, South Korea.

International Patents

1. Particle size sorting method and particle size sorting device for iron ore fines. Registration No: PCT/KR2013/004303.

2. Reducing gas blowing apparatus for fluidized reduction furnace. Registration No: PCT/KR2012/008302.

3. Apparatus for maintaining strip flatness. Registration No: PCT/KR2012/011553.

Domestic Patents (South Korea)

1. Runout Table and Roller. Registration No: 1015364760000.
2. Apparatus and method of monitoring operation data in Magnesium extracting process. Registration No: 1015280730000.
3. Powder providing device. Application No: 1020130163326.
4. Apparatus and method for measuring camber in hot rolling process. Registration No: 1020140169568.
5. Apparatus and Method for measuring shape of the steel strip coil. Registration No: 1020150064557.
6. Surface defect measuring apparatus and surface defect measuring system. Registration No: 1020150102485.
7. Wire rod with excellent segregation distribution and its manufacturing method. Registration No: 1020150186734.