論 文 の 内 容 の 要 旨

論文題目　Stokes Vector Based Polarimetric SAR Land Classification
（ストークスベクトルに基づく偏波合成開口レーダ地表分類）

氏　　名　　尚　方

Imaging radar has established itself as a capable and indispensable earth remote sensing instrument in the past two decades. At present, synthetic aperture radar (SAR) is intrinsically the only viable and practical imaging radar technique to achieve high spatial resolution. Fully polarimetric SAR (PolSAR) collects the full information of scattering matrix (HH, HV, VH, and VV) at every observed pixel. It is widely used in land classification fields.

Conventional classification algorithms for fully PolSAR data focus on analysis parameters for targets, such as scattering (S) matrix and coherency/covariance (C/T) matrix. Among these methods, the C/T based methods are the most active ones, since C/T matrix carries the important depolarization information of the targets. Although, the C/T matrix based classification methods are effective in many cases, there are still two main factors restricting their performances. Firstly, the C/T matrix is a parameter for target, not for scatted wave. It means that, partially polarized scattered wave information actually cannot be extracted physically from C/T matrix. To represent such depolarization information, in model-based decomposition methods, researchers introduce a volume scattering model. The expression of the model is switched according to the values of practical data to ensure high adaptability for various land situations. Nevertheless, depolarization phenomenon is caused in so many cases that finite number of volume models are not enough for all the situations. Then, sometimes, the depolarization information cannot be reasonably estimated. Secondly, In C/T matrix based decompositions, the averaged scattering mechanism described by the C/T matrix is decomposed as the sum of several elements. Such decomposition processes can hardly be unique, complete, and physical, simultaneously. For example, the H/A/α decomposition, a mathematical process, uniquely and completely decompose the T matrix. However, the decomposition results are not convenient to understand in physical way. On the contrary, the model-based decompositions, physical processes, decompose the T/C matrix into several elements corresponding to physical scattering models. However, since the models are not totally independent, such physical decomposition processes are usually not unique or complete.

Based on these considerations, developing an advanced algorithm which can use fully PolSAR data more sufficiently and effectively is a necessary topic. In this thesis, we propose Stokes vector based PolSAR land classification algorithms. Different from conventional ones, the proposed algorithm focus on the analysis parameters for scattered wave, the Stokes vector, directly. It is more powerful for dealing with the generally existing depolarization information. Therefore, the proposed algorithms have higher classification performance.

Firstly, we proposed the method of analyzing the averaged Stokes vector for PolSAR data. We show that the averaged Stokes vector can be calculate from PolSAR data. To calculate the averaged Stokes vector, certain polarization state of the incident wave needs to be supposed. With the change of the polarization states of the incident wave, we can have different averaged Stokes vector. By employing the Born-Wolf wave decomposition, the averaged Stokes vector can be expressed by three independent physical components: the total scattered intensity, the degree of polarization, and the completely polarized wave component. To illustrate the features of the three components, we observe the three components for a sample window of PolSAR data. The total scattered intensity and the degree of polarization are scalars varying with the polarization state of the incident wave, whereas the completely polarized wave component is a 3×1 vector varying with the polarization state of the incident wave. We can select special values, such as the maximum and the minimum values, of the scalar components to construct discriminators for classification. However, the application of the vector component is difficult. Then, the application method of the completely polarized wave component has been proposed. The completely polarized wave component can be expressed as a point on the Poincare sphere. With the change of the polarization state of the incident wave, the points will cover the whole Poincare sphere. Two special routes are selected to express the features. They are the zero orientation route and the zero aperture route. We prove that these two routes can be approximated by the ideal routes, and have observed the ideal routes for several typical geometries of targets. To make the principle of the Stokes vector based PolSAR land classification clear, we discuss the relationship and difference between the averaged Stokes vector and other widely used parameters. We show that, the averaged Stokes vector takes much more information than conventional C/T matrix. Especially, it is more powerful for dealing with generally existing depolarization phenomenon. Moreover, our averaged Stokes vector based process is very different from the Co/X-polarization power based process.

Secondly, based on the analysis of the three components of the averaged Stokes vector, we propose supervised Stokes vector based PolSAR land classification algorithm. The total scattered intensity is very sensitive to topography. This feature may cause difficulties in classifying the targets correctly.

Especially, in a supervised process. Therefore, in this supervised algorithm, we temporarily ignore the total scatted intensity component, and construct analysis parameters by only degree of polarization and completely polarized wave components. By representing the Stokes vector on/in the Poincare sphere geometrically, we construct two analysis parameters to describe the feature of a pixel in test area. They are, the position vector showing the averaged polarization state, and the variation vector presenting the polarization-state fluctuation in a small area centered on the pixel. We name the position vector and the variation vector together the Poincare sphere parameters. For analyzing the Poincare sphere parameres, we employ neural networks. The neural networks have high capability on dealing with fluctuation data. Moreover, they are very effective on the fusion of different types of analysis parameters. Because of the fluctuation of the Poincare sphere parameters and the fusion requirement of the position and variation vectors, the neural networks are expected to be a suitable analyzing tool. Using a real-valued feedforward neural network, we obtained successful classification results. Considering the multi-dimensional feature of the Poincare sphere parameters and the fact that, for the phase-sensitive remote sensing systems, the performance can be improved by employing complex-valued neural networks, we expect that the result of the classification in Poincare-sphere-parameter space can be also improved by using higher dimensional algorithms. With this idea, we use quaternion feedforward neural network. In experiments, we train the neural network with a set of teaching data for lake, grass, forest and town areas selected from the Fujisusono area. Then, by using the trained neural network, we generate successful classification results not only for the Fujisusono area, but also other test areas, such as the Suruga Bay area. In comparison with C/T matrix based methods, the proposed method has higher classification performance, especially on detecting forest and town areas. Moreover, the method is sensitive only to the polarization state of the reflected wave. Then, the result is not influenced by height information. With these advantages, the proposed classification method can, therefore, be used for complicated terrains.

Thirdly, we proposed unsupervised Stokes vector based PolSAR land classification algorithm. Unsupervised methods provide automatically interpretation for PolSAR data. However, strictly speaking, they are not complete classification processes. Therefore, for unsupervised algorithm, a more appropriate word interpretation is used instead of classification. We propose a method to extract discriminators from the averaged Stokes vector. Actually, we can have many different discriminators. In the proposed algorithm, we select five important ones for use. They are averaged intensity, averaged degree of polarization, perimeter degree, inclination degree, and arc asymmetry degree. The first two discriminators describe the averaging value of total scattered intensity component and degree of polarization component. The last three discriminators present the spatial attitude of the zero orientation and zero aperture routes of completely polarized wave component.

Then, based on the extracted discriminators, we have built four physical interpretation layers with ascending priorities: the basic layer, the low coherence targets layer, the man-made targets layer, and the low back scattering targets layer. The four layers together finally serve as the interpretation result of PolSAR data. In each layer, we focus only on targets with one certain physical feature. The information provided in each layer has unequal priority. The four layers together are already the interpretation results which can be used in the further classification process. Moreover, we can generate an intuitive final image by stacking the four layers according to priority order. A layer with higher priority is stacked on a layer with lower priority. We can find that, if a pixel is identified (colored) on several layers, the color in an upper layer will cover the color in a lower layer. It means that, only the information with highest priority is shown in final image. In this way, we obtain final interpretation image for Suruga bay Area. We also test the performance of the proposed unsupervised algorithm for Ebetsu city area and Tokyo harbor area. The results show that the proposed method has high interpretation performance, especially for skew aligned or randomly distributed man-made targets as well as isolated man-made targets. The origin of the strength of the proposed method for detecting man-made targets lies in the fact that it focuses on target structures rather than only scattering mechanisms themselves.

Finally, we briefly discuss the method of using Stokes vector for PolInSAR system. We show that, by constructing mixed-Stokes vector from the master and slave PolSAR data, the Stokes vector can be introduced into PolInSAR system.

In summary, in this thesis, a new classification algorithm system for fully PolSAR data is construct based on the Stokes vector. The proposed algorithms have high classification performance.