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論文内容要旨

Radar remote sensing is an essential technique for Earth observation, since it can measure Earth environments without touching them from space. Polarimetric SAR is one of radar which can measure polarimetric scattering property of targets by transmitting and receiving two polarized wave orthogonal to each other. Physical property of a target can be extracted from the polarimetric scattering property. However, acquired data analysis is not easy. The polarimetric scattering property depends on various physical parameters of targets such as shapes, dielectric constant, and so on. An appropriate data analysis method is necessary to acquire desired information on targets. This thesis provides analysis methods used for polarimetric SAR data. The objective is the characterization of ground surface objects. It is attempted how we can characterize and discriminate them effectively.

The second chapter provides basics of SAR and radar polarimetry. In this thesis, polarimetric SAR data is analyzed by two ways. One is the analysis utilizing the property of SAR system. The other is the polarimetric analysis. For the first analysis, sublook analysis is employed. In order to understand the meaning of the sublook, basics of SAR image is necessary. On the other hand, the polarimetric basics is needed from the fourth chapter. Characteristic polarization state and model-based decomposition is key ideas in the thesis.

Sublook analysis is given in the third chapter. Range sublook reflects frequency dependency on target scattering property, while azimuth sublook reflects radar look angle dependency. Coherent scatterers (CS) are important objects, since its scattering is rather simple and easy to be analyzed. In urban areas, range CSs have been well analyzed, while azimuth CSs have not been analyzed, since detected azimuth CSs are less than range CSs due to a large look angle dependency of buildings.

From the fourth chapter, polarimetric analysis is studied. First, rotation and ellipticity angles are analyzed. They are fundamental parameters to describe polarimetric scattering property of a coherency matrix. As for the rotation, the rotation angle to minimize the cross-polarization is studied. There are two definitions for that. One is the minimization angle only by the rotation, while the other takes the ellipticity into account. Moreover, the accuracy of the angle estimation is considered. From the observation, the angle of the first definition is sensitive to buildings, while the latter is robust to forest. Their property is explained by employing particle cloud model. Next, the ellipticity angle is for a coherency matrix is derived and analyzed. The difference depending on areas is seen. However, interpretation is difficult. Basically, the ellipticity is needed, when multiple objects with various orientations exist. A further analysis is future work. Finally, the simultaneous estimation of rotation and ellipticity is attempted. Resultant angles show robust and show the characteristics of areas well.

While the fourth chapter provides fundamental analysis of a coherency matrix, the fifth chapter gives an advanced method. In the fourth chapter, a coherency matrix is regarded as one scattering mechanisms. This is true in case of natural distributed scatterers. However, it is not applied in urban areas where targets with very different properties locate very closely affecting each other. In such cases, a coherency matrix needs to be decomposed into several scattering mechanism. Model-based decomposition allow us it. However, the non-orthogonality among pre-defined model mechanisms, the unique solution is not available. Especially, the volume scattering component is very important. If the volume scattering component is not estimated correctly, the other components estimated based on the volume scattering will be influenced. In order to estimate the volume scattering component correctly, a condition is proposed. The method examines the rest matrix after volume scattering subtraction from observed matrix. If the estimated volume scattering is correct, the rest matrix is physically reasonable. By checking correlation coefficients between polarizations, the validity of the estimation can be examined. Moreover, using that as a constraint, the power of the volume scattering to be estimated is constrained. By carrying out the decomposition within the constraint, more accurate decomposition is available. It is confirmed that the proposed technique constraint the volume scattering component effectively in buildings oblique to the range direction, while it preserve the volume scattering of trees. In fact, the proposed method is very similar an existing work. The difference is clarified. It is found that the proposed method is a part of the existing method. However, it can be equalized by adding one more condition. Moreover, the constraint can be derived analytically, while analytical solutions are not available by the existing work. The analytical solution allows a fast and accurate computation. In addition, the proposed method is applied to an arbitrary model.

In order to perform decomposition properly, many schemes have been proposed. Due to their different approach for solving, the solutions are different depending on the schemes. The latter part of the fifth chapter is the comparison of performance of several decomposition schemes. For a fair comparison, the same model set is employed commonly to all the schemes. Compared scheme is the four-component decomposition, nonnegative eigenvalue decomposition, and optimization. As a result of the comparison, it is found that the four-component decomposition tends to output the largest volume scattering of all, while the nonnegative eigenvalue decomposition yields the smallest volume scattering power. The optimization is in-between. Also, the imbalance between surface scattering and double-bounce is confirmed by the four-component decomposition and the nonnegative eigenvalue decomposition. This is due to the assumption employed in the scheme. On the other hand, the imbalance is not observed by the optimization. This is an advantage of the optimization. However, depending on the situation, the imbalance is desired. In such cases, the optimization performs worse. When decomposition is applied for data analysis, the property of scheme chosen must be cared for an accurate interpretation.

At last, the sixth chapter provides a combination of analyses by sublook and polarimetry. The constraint for volume scattering power was proposed in this chapter to suppress the overestimated power for oblique buildings. The proposed method utilizes azimuth sublook dependency of scattering mechanisms. Surface scattering and double-bounce can be either dependent or independent of azimuth sublooks, while volume scattering seems independent of that. Nevertheless, the estimated volume scattering power at buildings changes a lot with respect to azimuth sublooks, implying the overestimate. By assuming that the volume scattering power is perfectly constant with respect to azimuths sublooks, a further constraint is attempted. In order to avoid undesired constraint for targets that is reflection symmetry, the constraint is defined by adapting to the degree of reflection symmetry with a stationary indicator. The constraint is effectively strong at buildings, whereas the power is kept for natural distributed targets. This property is suitable to design a contrast between oblique buildings and trees.

論文審査結果の要旨

本論文は、偏波合成開口レーダ（POLSAR）のデータ解析法に関するものである。

第１章は緒論、第２章ではPOLSARの基礎事項をまとめている。

第3章では、異なる開口角を持つSARデータを用いて、サブルックコヒーレンスによって検知されるコヒーレント散乱体（CS）の性質を明らかにした。ドイツ航空宇宙センター(DLR)が運用する航空機センサE-SARは開口角が大きいため、アジマスサブルックではほとんどCSが検知できないが衛星センサTerraSAR-Xは小さな開口角を持つため、アジマスサブルックによって検知されるCSの数は、レンジサブルックによって検知されるものよりも多くなることがわかった。また、開口角が大きい時、アジマスCSの代わりとなる散乱体について提案した。２つの成果は1シーン内でより多くのCSを検知するのに役立つ。

第4章ではコヒーレンシー行列の回転角及び膨らみ角を用いた解析について検討している。一つ目はクロス偏波を最小化するもの、2つ目はco-polの差を最大とする回転角である。前者は二面体に対して精度良く推定でき Depolarizationの影響を受けやすく、後者はワイヤに対して精度よく推定でき Depolarizationの影響を受けにくいことがわかった。更に、膨らみ角と地物の関係について観察を行い、ターゲットごとに特徴的な値を示すことが明らかにした。これらの成果は、コヒーレンシー行列によるターゲットの分類・物性推定に役立つと期待できる。

第5章ではPOLSARモデル行列分解を検討した。まず物理的に妥当な分解結果を得るために、行列の半正定値条件による体積散乱電力の拘束条件を提案した。本条件から推定した体積散乱電力の検証及び取りうる最大値の導出を行える。最大値を求める際、既存の非負固有値条件を用いる類似研究が数値解を必要とする一方で、本手法は解析解を用いるので計算が速いなどの利点がある。次に異なる手法でのモデル行列分解の比較を行い、それぞれの違いを明らかにした。

第6章では、アジマスサブルックをモデル行列分解と組み合わせた地表分類法を提案している。都市部では体積散乱電力は過剰推定される傾向にある。体積散乱電力に加える制限を検討し、コヒーレンシー行列のサブルックに対する安定性に適応的な電力値を提案した。これにより、建物では体積散乱電力が3dB以上抑制されたのに対し、木々では2dB以下の拘束に抑えることができた。本提案手法はモデル行列分解の精度向上に資する。

本論文で提案された手法は、合成開口レーダデータを利用した地表環境の分類に有効であり、今後、物性値推定についての進展が期待できる。よって、本論文は博士(学術)の学位論文として合格と認める。