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論　文　内　容　要　旨

All across the world, people are facing a wealth of new and challenging environmental problems every day. These problems are not only natural disasters such as earthquake, typhoon, volcanic eruptions and tsunami, but also include human impact on the environment. Like the collapse of civil engineering structure such as building, bridge and tunnel.

In recent years, Ground Based Synthetic Aperture Radar (GB-SAR) has been studied as a potential method of environmental monitoring and disaster mitigation. Essentially, GB-SAR operates in the same principle as air- and space-borne SAR. GB-SAR can takes a measurement with much less time than other techniques over a widespread area at a higher spatial resolution. Furthermore, interferometric techniques can be applied by repeatedly scanning the scene in order to detect very small changes.

Chapter 1 briefly introduces the research background and motivations. Chapter 2 reviews the basic principle of GB-SAR and interferometry technique. The GB-SAR measurement for displacement estimation by interferometry technique were carried out for the demonstration. The displacement of the trihedral corner reflector was correctly estimated by interferometry technique after atmosphere correction. The mean error of displacement estimation of corner reflector after atmosphere correction is 0.22 mm. The GB-SAR measurement with interferometry technique can accurate estimate the small displacement changes. Moreover, the GB-SAR interferometry technique was used to monitoring Arato-zawa post landslide which located at Kurihara city, Miyagi prefecture Japan. The landslide in this area was triggered by a big earthquake in Miyagi and Iwate prefectures in 2008. The slide area is approximately 1300m in length and 900m wide. Monitoring of the site is required to ensure the safety around the area. GB-SAR survey is being carried out since June 1st, 2012. GB-SAR system is placed about 400m far from the slope and it covers 300m in azimuth and 500m in range. Two long term observations were carried out. Displacement maps of each period and each month are obtained and large displacement changed caused by snow are observed. These GB-SAR results have been useful for the interpretation of long-term stability of this post landslide.

Chapter 3 focuses on coherent scatterers selection in GB-SAR. In GB-SAR measurement, the information cannot be extracted from all pixels within the area under study; due to decorrelation phenomena, only a limited number of pixels along the whole dataset are useful. The detection of high-quality scatter has thus become an important topic with a wide range of applications for GB-SAR monitoring. These pixels called coherent scatterers. In this chapter, an extend work to select coherent scatterer from single dataset with full-spatial resolution is discussed. The sub-images were generated by interleaved pick out the data along frequency direction of each azimuth acquisition point. The main advantage is keep the resolution of sub-images and finally full resolution coherent scatterer's map will be obtained. The limitation is shortened the observation range involved in the reduction of frequency points of sub-spectrum. Once the sub-images have been obtained, their spectral behavior is characterized with the spectral correlation coefficient. At this stage, the entropy values of each pixel of the sub-images are available for evaluating spectral correlation coefficient. The performance of the proposed method has been evaluated using real GB-SAR data acquired in both urban and nature areas. The coherence scatterer maps selected by the proposed method were compared with the so-called classical approach (dispersion of amplitude method). Both methods produce similar coherent scatterer maps, and the trihedral corner reflectors that were placed in both urban and natural settings were successfully selected by the proposed approach. However, coherent scatterers with short temporal characteristics were successfully selected by the proposed approach and were missed during long term observations.

Chapter 4 aims to develop a new imaging algorithm to satisfy the requirement of GB-SAR monitoring. In this chapter, an efficient and accurate GB-SAR imaging algorithm based on fractional Fourier transform (FrFT) was proposed. The mathematical formation of this algorithm and the optimal focusing condition are given in this chapter. This proposed algorithm is a kind of modify diffraction stacking method and focused reflectivity map into a polar format. The key point of this algorithm is that the spatial frequency along linear rail could be optimal represent at certain rotated angle fractional Fourier transform. This property makes only 1-D fractional Fourier transform is required for azimuth compression. Before applying this algorithm, 1-D IFFT is needed to transform the raw data into time domain signal. Then the optimal rotated angle for each range should calculated. After that, 1-D FrFT should applied with a certain rotated angle for each range. Finally, the polar format GB-SAR image is obtained. Both numerical simulations and GB-SAR experiments show that the quality of the imagery obtained with proposed approach is perfectly comparable to that of well-known diffraction stacking, no matter near- or far-field. Moreover our approach has the lower computational cost, which is an important request for GB-SAR applications. The numerical simulations have shown that the algorithm can be used with ultrawideband and high frequency GB-SAR system with excellent results.

Furthermore, in Chapter 5, a new way to reconstructed GB-SAR image by compressive sensing in fractional Fourier domain was proposed. Compressive sensing can reconstruct the sparse signals even if a number of samples much lower than the requirement. In the previous discussion, GB-SAR processing could be formulated as 1-D Fourier transform along range and 1-D fractional Fourier transform along azimuth. So, in this chapter, we applied this novel GB-SAR processing to reconstruct GB-SAR image by compressive sensing. Three random sampling strategy were discussed and the reconstructed results were shown in this chapter. The most common random sampling strategy which is done by choosing random samples from whole spatial-frequency GB-SAR data. Another form of random sampling is random frequency sampling and reconstructed imaging can be started by using received echo signal at any look angle of antenna. The other one is random spatial data collection and it starts with the echo signal’s first row which includes whole synthetic aperture aspects. This random spatial data collection strategy for all frequency has much more practical meaning in GB-SAR. It will save a lot of acquisition time, which is very important for environmental monitoring. The reconstructed images were compared with that in Fourier domain. The simulation and experiment results demonstrated that to reconstructed GB-SAR image by compressive sensing in fractional Fourier domain could recover more targets than that in Fourier domain for sampled in spatial domain and random samples from whole spatial-frequency data.

Chapter 6 is for applying polarimetric analysis to deformation monitoring in GB-SAR. The polarimetric responses hold the maximum information of the scatters. And all the polarimetric information could be written into scattering matrix. This chapter shows the two application of polarimetric analysis in GB-SAR monitoring. One is full polarimetic analysis for target identification during GB-SAR monitoring. We applied polarimetric analysis to the measurement of Railway Bridge vibration monitoring by GB-SAR. The polarimetric analysis can help us to clearly identify the reflection comes from which part of bridge. And combine with interferometric technique, the vibration of each position of bridge while train was passing through were are got. It is very useful tool when we have a complicated monitoring environment. Another aspect is temporal polarimetric analysis for deformation monitoring. Simply, we add the responses of all channel together and analysis the entropy value along several GB-SAR measurement which acquired in Sendai airport in two different period. One is running period and another one is no running period. This entropy value shows that in the no running period, the scatter mechanism was stable. But, in the running period, the scatter mechanism changed a lot.

Finally, the contributions and innovations of the whole thesis, and further perspectives are summarized in Chapter 7.

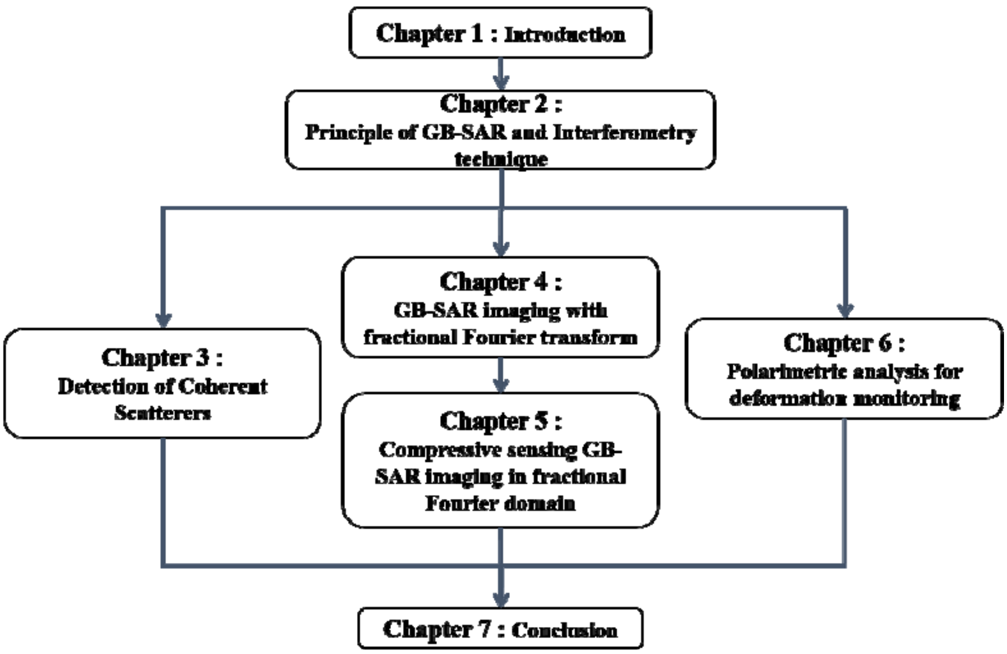

Figure 1 Structure of this thesis.

（別紙）

論文審査結果の要旨及びその担当者

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論文審査結果の要旨

地表設置型合成開口レーダ（GB-SAR）は電波を利用し遠隔的に対象物の形状を捉え、表面の微小な変位や振動を繰り返し計測できる技術である。10 年ほど前から実用的な利用が世界中で始まっているが、信号処理をはじめとしてより有効に計測データを利用するために解決すべき問題が数多く残されている。本論文は GB-SAR に関して信号処理の新たな開発と実計測への応用に関する研究をまとめている。

本論文は７章で構成されている。

第１章はイントロダクションである。第２章は GB-SAR の基礎的な技術、信号処理アルゴリズムをまとめている。

第３章では干渉計測で重要なコヒーレント・スキャッタラー(CS)を抽出するために、１枚の GB-SAR 画像をサブイメージに分解し、サブイメージ間の複素コヒーレンスを使って行う手法を開発した。開発した手法により、従来 10 回以上の計測を要した処理が１回のデータで行えるようになり計算時間が飛躍的に短縮できる。

第４章ではフラクタル・フーリエ変換という数学手法を用いることで、合成開口レーダ処理で計算時間を要していた近距離のイメージングを、近似による精度劣化を起こすことなく高速に演算できる手法を見いだした。提案手法を実計測データへ適用することで有効性を立証した

第 5 章では、逆問題を疎なデータから解くコンプレッシブセンシングの手法を利用し、合成開口レーダ処理を効率的に行えること示し、実データに対して適用した。この手法は一種の超分解能法でもあり、高分解能画像が得られることを明らかにした。

第６章は、GB-SAR の実用的な応用例として、橋梁の振動計測などに適用した。同時に、計測対象の位置を正確に把握するため偏波情報を利用することを提案している。

第７章は結論である。

本研究では、繰り返し計測できる GB-SAR の情報を、いかに高精度、高分解能を維持しつつ高速にイメージングができるかという問題に対し、フラクタル・フーリエ変換を取り入れたアルゴリズムを提案した点で、非常に学術的な価値が高い。またこの手法を用いることで、従来、オフラインの後処理でしかイメージを得られなかった航空機や衛星搭載センサでオンボードのデータ処理が可能になる可能性がある。

また高速なデータ処理は振動計測にも適しており、地滑り、火山計測や社会インフラ計測など環境モニタリングへの応用範囲は極めて広い。こうした観点から本研究は環境科学に資するところが大きい。

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。

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