An Implementation and Configuration of Ground Based Synthetic Aperture Radar for Environmental Monitoring

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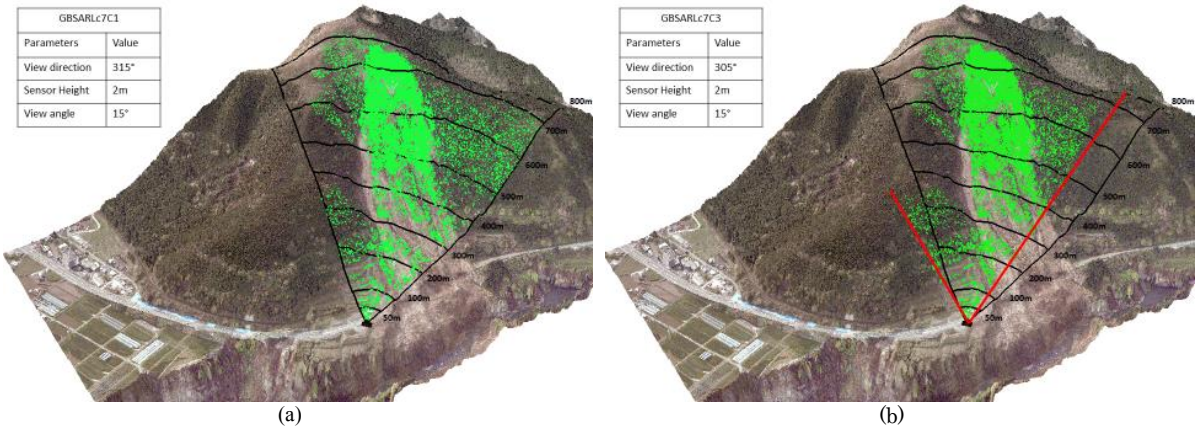
論文内容要旨

Radar remote sensing technique gives accurate information for environmental monitoring. Unlike space borne and air borne remote sensing techniques, the Ground-Based Synthetic Aperture Radar (GB-SAR) can be identified as most sophisticated remote sensing technique which can deploy with higher spatial and temporal resolution. However, prior to the deployment of such remote sensing technique to monitor the terrain displacement phenomenon, the technical feasibility assessment used as a prognosticate tool to uncover the strengths of the proposed technique by objectively and rationally. In this study, the applicability of GB-SAR as an early-warning system for landslide detection was informatively discussed. The effectiveness of Differential Interferometric SAR (DInSAR) technique used in GB-SAR has a higher correlation with the geography of the monitoring location. Therefore the system compatibility assessment gives the highly considerable result to select the most appropriate remote monitoring method and its realm, before any hardware deployment.



(a) (b)

Figure 1. Estimated GB-SAR illumination of configuration (a) 7C1 and (b) 7C3 by simulation

In the preliminary context, a 3D model was created using LiDAR survey and expected locations for GB-SAR installation were testified. The 3D simulation was carried out to estimate the expected illumination from each of the proposed locations. The location shown in Figure 1 was selected for system installation by considering optimum illumination from expected zones. Then the hardware

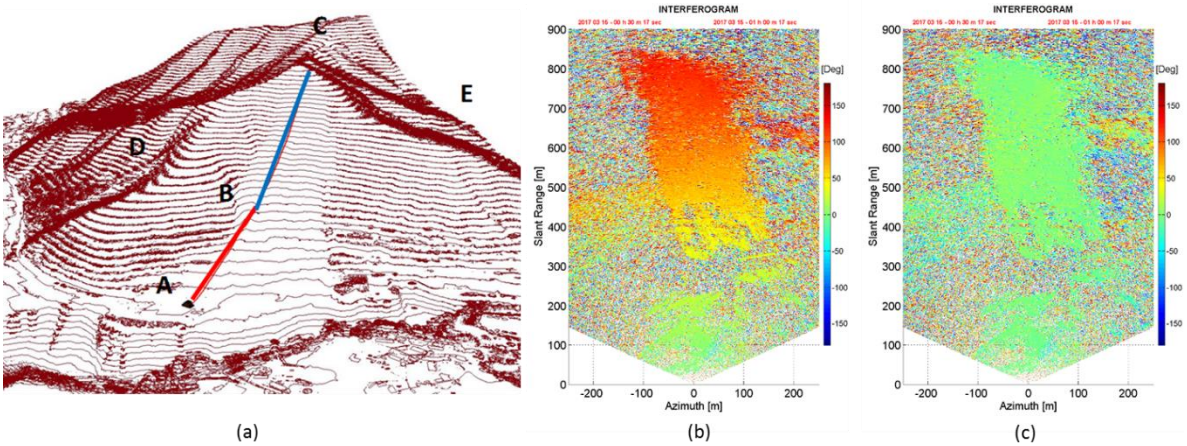


Figure 2. (a) The terrain model depict the elevation stages AB and BC. The interferograms of Minami-Aso GB-SAR monitoring station (b) before (c) after atmospheric correction.

configuration parameters such as platform height, radar line of sight direction and view angle were estimated for the best-reflected power and the optimum ground illumination as shown in Figure 1 (a) and (b). The GB-SAR system was installed and data acquisition was started from mid of January 2017. Unlike on flat terrain, the GB-SAR deployment in a mountainous area become challenging task due to continuous change of meteorological parameters such as atmospheric temperature, pressure and relative humidity. In this background, a new atmospheric phase compensation method was proposed based on the spatial modeling of the GB-SAR observation area as shown in Figure 2 (a). The proposed Two-Stage Semi-empirical algorithm (TSSA) for atmospheric artifacts removal is compared in Figure 2 (b) before and Figure 2 (c) after applying to interferograms in the Minami-Aso GB-SAR. The TSSA is based on the statistical method, and no atmospheric pressure, temperature or humidity data were required for interferometric phase correction. Therefore TSSA can be used to enhance the applicability of GB-SAR system with a minimum number of background data and the real time monitoring. The system can be used to work as a stranded alone system for remote monitoring in a highly dynamic environment.

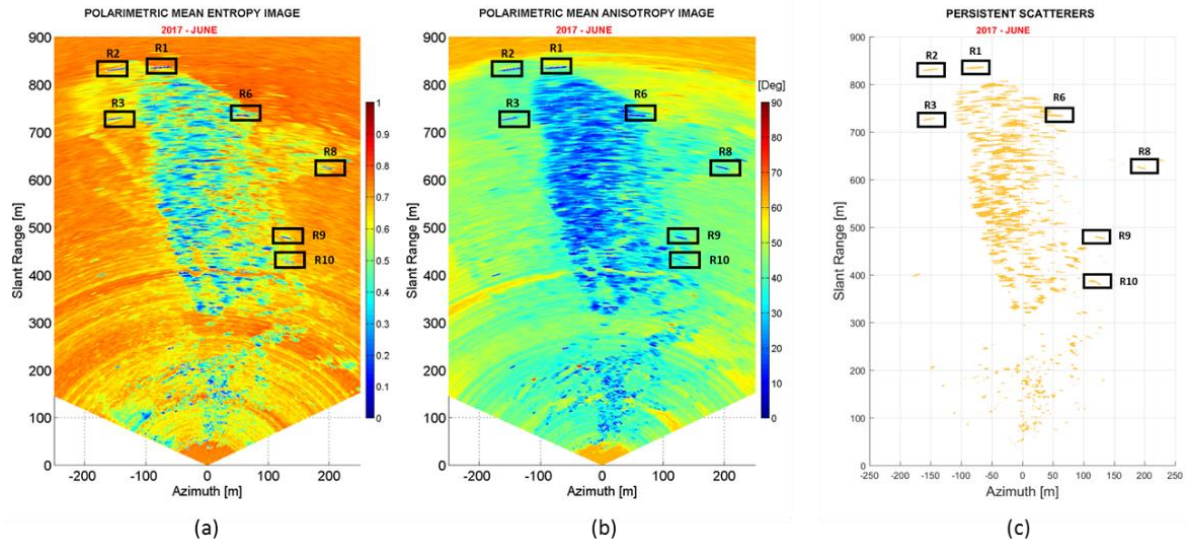
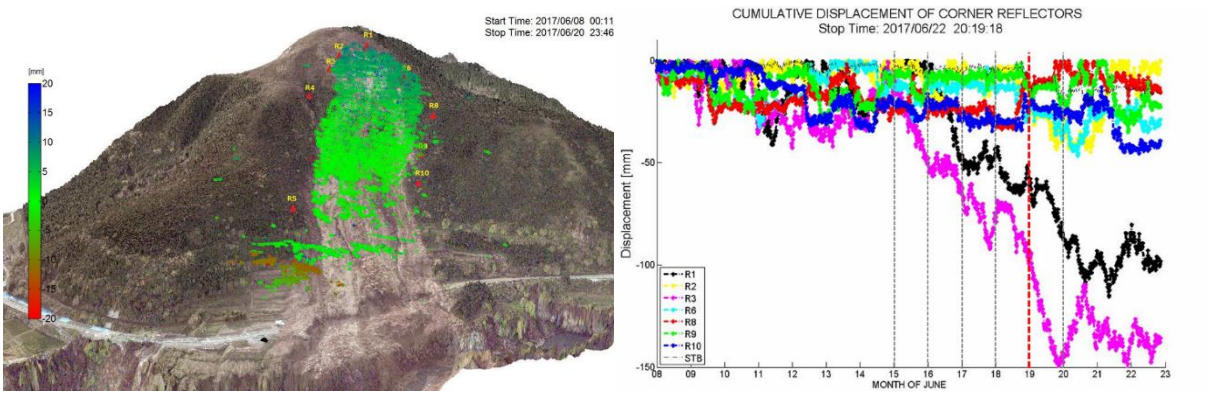


Figure 3. (a) The polarimetric entrophy H (b) The polarimetric alpha angle α (c) The results of the proposed criteria used for CS point selection by H/α plot



(a) (b)

Figure 4. The developed (a) Real time 2D displacement system (b) Displacement inside the forest

Furthermore, the concept of coherence (CS) scatters estimation is one of the main topics in DInSAR monitoring process. It will guarantee the reliability of displacement measurements estimated by the GB-SAR system. In this study, the new criteria for CS estimation was proposed based on eigenvector and eigenvalue analysis of 3 x 3 coherency T3 matrix by the fully polarimetric GB-SAR system. It can be used to detect the most stable locations in a minimum number of GB-SAR data acquisitions. The results show that the proposed method can be used to identify the CS location by a limited number of SAR scanning. Further, it gives a reliable estimation for far range objects, the corner reflector R2, R3, which could not be clearly visible by conventional CS estimation method. Since the amplitude of the power image decrees with range direction, most of the power reflected over 1000m is happen to change eventually irrespective for their stability. This was adversely affected by conventional DA index method by addressing the estimated stability of far field objects. This effect was minimized by the proposed CS estimation method which considers the stability of amplitude and the phase component of the backscattered signal.

We have developed new landslide monitoring and early warning system to retrieve the displacement information to the people who are daily involved with road reconstruction construction in Minami-Aso post-disaster recovery site. The system monitors the real-time displacement of the entire landslide area, the real-time displacement inside the forest canopy and automatic landslide early warning system which sends an email notification about the locations which have a higher rate of displacement. The GB-SAR has a great potential for render real time and the reliable information of sub-millimeter level displacement in the 2D plain which no other sensor can obtain so far. Currently, the interferometric GB-SAR is utilized for the real time monitoring of the open pit mining and landslide monitoring. This system can propose as a safety tool for a large scale construction site in future. By different operational modes, a system also deployed as a quality estimation tool by vibration monitoring, structural health estimation so on. Prior to those field deployments, Estimation of incident angle, incident power, can be optimized by computer simulation model in future. Furthermore, there is not many research work based on the fully polarimetric GB-SAR sensor. Fully polarimetric radar signal can use to estimate soil condition such as soil moisture. This would be very interesting research area in future in order to predict most probable area to trigger land slide within the range of observation.

（別紙）

論文審査結果の要旨及びその担当者

論文提出者氏名	Amila　Thilanka　KARUNATHILAKE
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論文審査結果の要旨

本論文はマイクロ波リモートセンシング手法である地表設置型開口合成レーダ(GB-SAR)計測を用い、南阿蘇などの地滑り地域を対象に、減災対策への応用を通じて総合的な環境評価手法に関する研究をまとめたものである。

本論文は8章より構成される。
第1章は緒論、第2章はGB-SARの基礎と偏波レーダ計測技術のまとめである。
第3章は地滑りなどを対象としたGB-SAR計測におけるレーダ装置設置に関する具体的な問題点をまとめた上で、GISを利用して設置場所を決定する手法を提案した。
第4章では、GB-SAR実用化の上で現在最も大きな問題とされる大気補正に関する理論的、実験的検討を行っている。大気中の水蒸気によって電波の伝搬速度がわずかに変化するが、これが干渉 SAR 解析では対象物の変位と識別ができない。特に山岳地域では急な天候の変化や風の影響で大気の影響が極めて強い。本研究では南阿蘇の気象状態を解析した上で、従来用いられてきた均一大気近似を2段階の近似に変えることを提案し、これにより従来法に比べ正確に地表面変位を捉えることができることを実験的に示した。
第5章では干渉SARを行う上で参照とする安定した反射点(CS)を、SAR画像中から偏波情報を利用して選定する手法を提案し、実データに適用した。これにより実計測で問題となる植生などレーダ計測の障害を有効に取り除くことができることを示した。
第6章では本研究で得られた知見に基づき、熊本県南阿蘇村に設置したGB-SARを利用し実際に地滑り警報を発信するための検討を行った。そのためにデータ取得間隔、データ送信方式、干渉データからの異常自動検知と早期警報の発信などについて詳細に検討し、社会実装に必要なシステムを構築した。第7章では、こうした手法をスリランカに適用することを想定したフィージビリティ・スタディを行っている。
第8章は結論である。

本研究では、スリランカと熊本県阿蘇地域で共通する多雨に起因する土砂災害の減災を目的に、地表設置型合成開口レーダ(GB-SAR)による斜面計測を、基礎から実践に至るまで実施した。工学的なレーダ研究を地域環境に適用するように利用するための手法と取得データを地域住民に伝達するまでの手段を含めた多様な環境問題に資するための課題を明確化し、その解決手段を示した。本論文はマイクロ波リモートセンシング技術による土砂災害の減災を目標とし、環境計測手法について非常に大きな成果を上げつつ、学術的意義の高い研究を達成している

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。