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研究課題名（和文）Detection of Buried Objects by Synthetic Aperture Radar Imaging for Improved Disaster Response

研究課題名（英文）Detection of Buried Objects by Synthetic Aperture Radar Imaging for Improved Disaster Response

研究代表者
KOYAMA　CHRISTIAN（Koyama, Christian）

東京電機大学・理工学部・研究員

研究者番号：４０７０４９６１

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研究成果の概要（和文）：飛行機、衛星と地上に置かれたポラリメトリSARデータから見つける新しい方法とアルゴリズムを開発しました。 新しいウルトラワイドバンドポラリメトリGBSARシステムを開発しました。40以上の表面下の物をうまく見つけました。埋められた物を分類する新しい方法は、開発されました。二つの研究記事を出版されました。

研究成果の概要（英文）：We have developed new methods and algorithms to detect, localize and classify buried objects from airborne, space borne and ground-based polarimetric SAR data. We have developed a new polarimetric GB-SAR system which allowed, together with the use of state of the art airborne and space borne SAR data from Japanese sensors operating at different radar frequencies, to successfully detect more than 40 subsurface objects. A novel approach to classify buried objects based on their polarimetric signatures was proposed. For the first time ever, we successfully obtained SAR data from bistatic ground-based/airborne experiments. The results demonstrate the potential for the detection and localization of buried objects from fast, aerial radar measurements which can contribute to drastically improve disaster response after events like earthquakes, tsunamis, landslides, volcanic eruptions or avalanches. Two journal papers were published and one more is being prepared for submission.

研究分野： Radar remote sensing

キーワード： GB-SAR　GPR　Polarimetry　Disaster mitigation　Radar imaging　Target detection　Synthetic aperture radar

１．研究開始当初の背景

Many tragic events caused by different disasters in Japan caught attention in recent years. Massive landslides in the Kumamoto region destroyed whole build-up areas and buried many people, cars and other objects. The eruption of Mount Ontake in Nagano prefecture buried more than 50 people under ashes. The search for those victims submerged below ground is usually very difficult requiring many personnel for the search and rescue operations. In the frame of this research we supported the police in the post 3/11 search for bodies and objects at different beach sites in Fukushima, Miyagi and Iwate prefectures by using our advanced Radar equipment. Synthetic Aperture Radar (SAR) imaging has due to its penetration capabilities into the subsurface combined with the extremely fast acquisition time, a high potential for improved disaster responses in terms of detection and localization of buried victims and objects. Today many advanced airborne and space borne SAR systems with high resolution and polarimetric capabilities are available. They are suitable to develop a method for improved disaster response over large areas in fast time. SAR data of two different airborne sensors were used through our principle investigator (PI) contracts with the operating agencies. Multiple X-band SAR data acquired by NICT's Pi-SAR2 and L-band data acquired by JAXA's Pi-SAR-L2 were available in the research period. Both systems have full polarimetric capabilities and can image a wide area with high resolution. L-band has a very good penetration into the subsurface. The super high resolution of the X-band system could detect some buried objects from small anomalies in the surface conditions. In addition, space borne data from the Japanese state-of-the-art L-band SAR satellite ALOS-2 was used. A new dedicated ground-based (GB) SAR system was developed and used for subsurface detection experiments. The development of the new GB-SAR system was based on experience gained from the development of the polarimetric UWB GB-SAR system for high-resolution subsurface imaging within the last two years.

２．研究の目的

The overall purpose of the proposed research was the improvement of disaster response and search and rescue operations in areas submerged by ashes, sand and soil after catastrophic events like earthquakes, tsunamis, landslides, volcanic eruptions or avalanches. The research aimed on the development of methods to detect persons and objects buried below ground by means of airborne, space borne or ground borne SAR imaging. In the frame of this research a new dedicated ground-based SAR system was being developed. This system can operate in the same frequency bands as the airborne and space borne sensors and can be used as aerial imaging system in cases when airplane or satellite overflights are not available. Ready-to-use maps indicating the locations of detected subsurface objects were produced.

３．研究の方法

(1) Development of a polarimetric GB-SAR system

Large type Vivaldi antennas were designed and simulated by using dedicated software (CST Microwave Studio). After the design of antennas suitable for radar measurements in the L-band (~1.25 GHz) and the X-band (~9.55 GHz), the prototypes were manufactured. The antennas were tested in the anechoic chamber and the antenna characteristics were measured for the later signal processing. Four antennas were used to build a polarimetric antenna array. The array was connected to a 4-channel VNA by the semi-rigid coaxial cables. Using a small antenna positioner, in-door tests and experiments with subsurface targets were carried out in the sand pit. Based on measurements in the anechoic chamber and sand pit, the system parameters will be optimized and polarimetric calibration of the system will be performed.

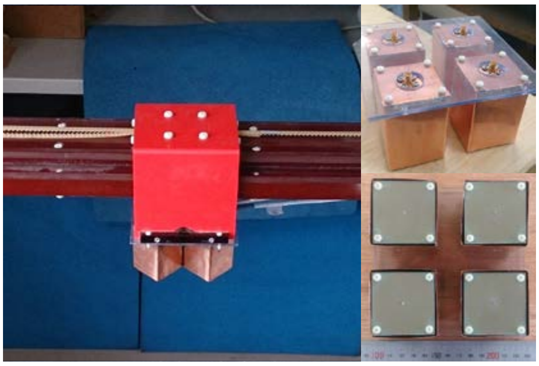

Fig. 1.　The polarimetric UWB GB-SAR system with circular polarization spiral antenna array.

(2) Subsurface reflector experiments with airborne and space borne SAR imaging

A variety of different sized and shaped radar reflectors were manufactured, including simple flat plates, dihedral and trihedral corner reflectors. These reflectors were installed below ground in different soil types at various locations. The selection of the most suitable locations in the study area was based on multi-temporal SAR data analysis using the available airborne SAR images. The in-situ soil permittivity at the time of the ALOS-2, Pi-SAR2 and Pi-SAR-L2 data acquisitions was measured and recorded by using the TDR sensor. In addition to the near-surface TDR measurements, CMP data was acquired by GPR antennas to measure the vertical permittivity variations in the subsurface.

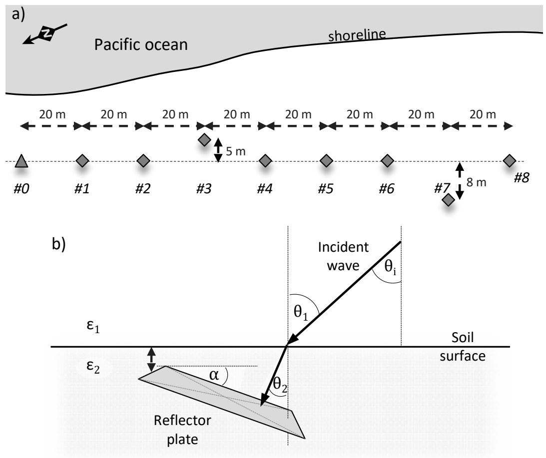

Fig. 2. Sketch of (a) the arrangement of above- and below-ground reflectors and (b) the installation of flat plates in the soil by considering Snell's law.

(3) Experiments with the developed GB-SAR system

The developed GB-SAR system were used to conduct experiments with buried subsurface corner reflectors in the field. Additional small corner reflectors were built and installed at an intensive test site at Yuriage. Mounting the system to the 2D vertical planar scanner allowed measurements with a wide variety of observation parameters. GB-SAR images were acquired from different observation heights and for different incidence angles, with different scanning speed and sampling intervals. For the experiments, the soil permittivity was changed by wetting the soil. The actual soil moisture states were measured by TDR sensor.

(4) Bistatic ground borne/space borne and ground borne/airborne SAR experiments

In addition to the normal GB-SAR measurements we carried out bistatic ground borne/airborne SAR experiments during Pi-SAR2 and Pi-SAR-L2 overflights and bistatic ground borne/space borne experiments during ALOS-2 passes. For these experiments, the developed GB-SAR system acted as receiving polarimetric antennas only while the incoming polarimetric signals were transmitted by the airplane and satellite based antennas, respectively. This allowed acquiring novel kind of SAR imaging data. The data was used to investigate the potential to detect subsurface objects from bistatic SAR configurations.

(5) Development of algorithms for detection and location of buried persons and objects

Based on electromagnetic reflection and transmission theory combined with the large data base of experimental data and state-of-the-art polarimetric SAR images, semi-empirical algorithms to detect and localize persons and objects buried below ground were developed and tested. These algorithms were used in an optimized processing chain for a fast and automated screening of a disaster affected area in order to produce ready-to-use maps of detected locations which can be provided to the disaster response and rescue teams.

４．研究成果

(1) Buried target detection from air- and space borne SAR

Fig. 3 exemplarily shows a profile of Pi-SAR-L2 measured backscattering coefficients over the reflector targets. The imaging date was more than 3 weeks after burying the metal sheets, thus we assume that effects from soil disturbance do not occur in the image. The sigma naught values were obtained from the geocoded images with pixel resolution of 2.5 m. As can be seen, the detection of the buried flat plates is not easy. While the above-ground targets are naturally obvious in the given profile, only one of the most shallow targets (reflector #5) is distinguishable from the clutter at first glance.

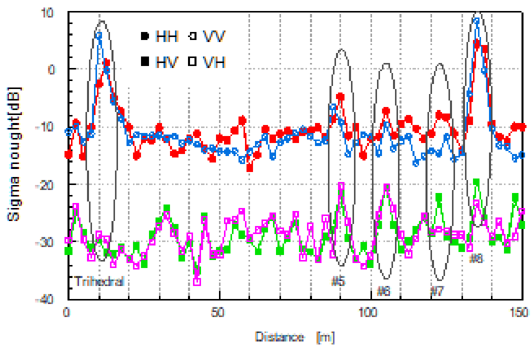

Fig. 3. Pi-SAR-L2 backscattering coefficients profile for the above- and below-ground reflector targets at the sand beach.

Taking a closer look at applying a threshold value of −9 dB, we might also detect reflectors #6 and #7. The other reflectors, even though some were buried at shallower depth, were failed to detect. One reason for this might be the fact that reflectors #1 to #3 were located too close the sea shore where the penetration depth is very low as was later confirmed by GPR measurements. The preliminary analysis of spaceborne ALOS-2 PolSAR image data failed to detect any of the subsurface targets. This is most likely due to three main reasons i) the reduced image quality with higher speckle noise as a result of the 4-bit data compressed data quality, ii) the somewhat shallower incidence angle of 33.1 deg. as compared to the 40 deg. AOI of the Pi-SAR-L2, for which the reflector orientation was optimized, and iii) a reduced imaging resolution of approx. 3m by 3m in the SLC image which is potentially too coarse. That is the 1 m2 metal plate makes up only about 10% of one pixel area, and thus its contribution to the pixel RCS is not strong enough. However, it should be mentioned that the September 11 ALOS-2 image was acquired during the Cal/Val phase of the newly launched satellite, and the routine operation did not start before November. Hence, the Level 1.1 SLC product as obtained from JAXA might not be perfectly calibrated and a proper reprocessing could possibly improve the detection capability. This reprocessing of the ALOS-2 data is ongoing.

(2) Subsurface target detection from ground-based SAR

Fig. 4 shows an image result obtained by the UWB GB-SAR system. The SAR processed vertical slice image (B-scan) shows the responses of 4 thin metal wires located at various depth, 5 mm in diameter and aligned along the y-axis. The data was taken in a sand pit with a permittivity of approx. 5, similar to that of the natural sand beach. Note that for the sake of faster imaging speed, the data was acquired with the reduced imaging resolution as compared to the optimal resolution obtainable with the developed system. As can be seen, all targets were successfully detected.

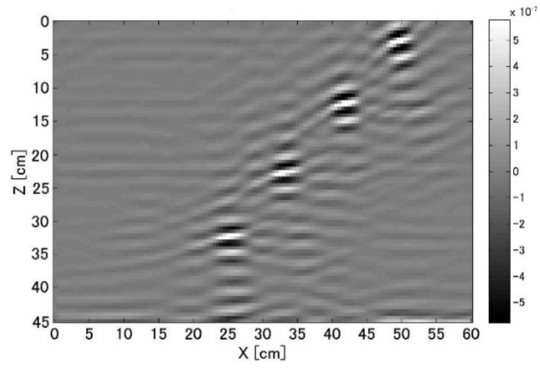

Fig. 4. SAR processed vertical slice (B-scan) of buried dipoles at four different depth as measured by the UWB GB-SAR in VV co-polarization.

(3) Subsurface Target Classification

In the development of a subsurface target classification scheme, we used the fundamental polarimetric signatures approach. In the next step, target classification by more handy approaches based on other polarimetric decomposition schemes, e.g. the entropy and mean alpha angle parameters derived from the eigenvalue-eigenvector-based decomposition, will be tested. Fig. 5 shows the polarimetric scattering signature obtained from the Pi-SAR-L2 data for the flat metal plate reflectors. The signatures for the above-ground reflector #8 are almost equal to theoretic values. The signatures for the most shallowly buried flat plate #5 already show a considerable amount of distortions. However, this result indicates that the polarimetric scattering mechanism still holds valuable information about the shape of the buried target.

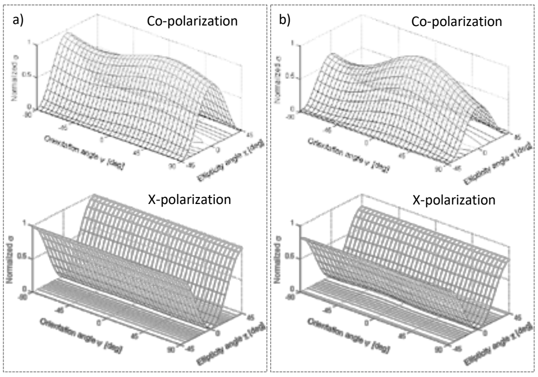

Fig. 5. Polarimetric signatures for flat plate reflectors as measured by Pi-SAR-L2 for (a) above-ground reflector #8 and (b) buried reflector #5

Fig. 6 shows two examples of polarimetric signatures as measured by the UWB GB-SAR system, one for (a) a subsurface dihedral corner reflector and the other one for (b) the buried dipole discussed in the foregoing section. The depth of the targets is approx. 10 cm below-ground. The results shown are calculated from the 5-GHz SLC data which were extracted from the full 10-GHz bandwidth data set. Obviously, both signatures show a considerable amount of distortions from their theoretical form [12]. Nevertheless, the distinct scattering characteristics for these canonical targets are still well recognizable. This suggests that in the near-range imaging case, even at relative high frequencies we still can obtain valuable polarimetric target scattering information.

The results obtained in this research showed that we can not only detect buried objects from aerial low-frequency SAR images, but also that the polarimetric analysis of scattering behavior can be used to obtain more detailed information about the shapes of the subsurface objects allowing for a basic classification of detected targets. Furthermore, for the near-range imaging case, we can obtain valuable polarimetric scattering information from buried targets even at relative high frequencies. However, it should be considered that for the airborne and especially space borne sensors the detection of subsurface targets by their RDS is very difficult due to the limited imaging resolutions of low-frequency SAR systems.

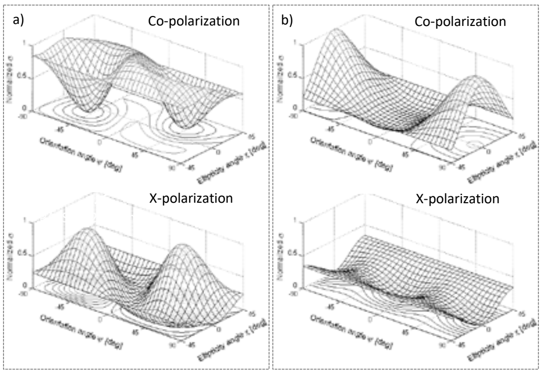

Fig. 6. Polarimetric signatures for (a) a subsurface dihedral corner reflector and (b) a vertical dipole as measured by the UWB GB-SAR.

The findings made in this study demonstrate the potential for the detection and localization from fast, aerial radar measurements which can contribute to drastically improved disaster response and rescue operations after events like earthquakes, tsunamis, landslides, volcanic eruptions or avalanches. Ready-to-use maps of buried objects constitute a whole new service for rescue workers and agencies involved in disaster response operations.

５．主な発表論文等
（研究代表者、研究分担者及び連携研究者には下線）

〔雑誌論文〕（計　３件）

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(1) C.N. Koyama, M. Sato, and M. Shimada, "Quantitative Above Ground Crop Biomass Estimation using Ground-based, Airborne and Spaceborne Low Frequency Polarimetric Synthetic Aperture Radar," 2016 AGU Fall Meeting, Dec. 12-16, San Francisco, CA, USA, 2016.
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〔図書〕（計　　件）

〔産業財産権〕

○出願状況（計　　件）

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権利者：
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〔その他〕
http://magnet.cneas.tohoku.ac.jp/satolab/satolab-j.html

６．研究組織
(1)研究代表者
小山　クリスチャン（KOYAMA, Christian）
東京電機大学・理工学部・研究員
研究者番号：　４０７０４９６１