Advanced Earthquake Damage Assessment in Post-Event Synthetic Aperture Radar Imagery Using Statistical Learning

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学位論文題目　Advanced Earthquake Damage Assessment in Post-Event Synthetic Aperture Radar Imagery Using Statistical Learning (統計的学習理論による災害後 SAR 画像からの地震被害把握の高度化)

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論 文 内 容 要 旨

1. Introduction

Nature hazards, especially earthquakes, are regarded as one of the deadliest challenge to the human lives and property. To make strategies for deploying disaster response accurately and efficiently, the affected built-up areas and the damage degree information are highly needed. The increasing perspective of role of large scale earth observation techniques in disaster monitoring and quick response has stimulated much attention in the employment of satellite-based approaches for earthquake damage assessment. Accordingly, rapidly and accurately assessment of the damage extent in an operational way are highly required. As we know, the availability of the appropriate remote sensing data is vital to the operational disaster response. However, there is incompatible bottleneck associated with the mainstream satellite platforms, through sensor types or observation mode. Such unavailable and/or incompatible problems of remote sensing data sources severely restrict the operational use of current mainstreamed multi-temporal remote sensing image based change detection disaster response technology. Regarding satellite-based approaches, synthetic aperture radar(SAR) remote sensing technology is considered to be an effective disaster assessment technology because of its characteristics of light and cloud cover independence. Several preliminary trials have been proposed for extracting the earthquake induced damage information using only post-event SAR data. However, these methods have great limitations in terms of accuracy, speed and applicability. Therefore, the main purpose of this study is to develop a high accuracy, rapid and high applicable method for assessing the earthquake damage using only post-event SAR data.

2. The specific tasks addressed in this thesis

This thesis consists of three main contributions of using only post-event SAR data to assess the earthquake damage,1) Investigating radar scattering characteristics of earthquake damage in dual-polarimetric ALOS-2/PALSAR-2 image, 2) Developing an object based damage assessment method using machine learning from only post-event ALOS-2/PALSAR-2 image, this technique has been developed based on the 2015 Nepal earthquake. 3) Developing an object based damage assessment method using deep learning, this technique has been developed based on the 2011 Tohoku earthquake and tsunami disaster.

2.1 Radar scattering characteristics of earthquake damage in dual-polarimetric ALOS-2/PALSAR-2 image

Research background & Purpose

The latest spaceborne High Resolution SAR sensors onboard the ALOS-2 satellites could provide the SAR data products in dual-polarimetric mode with spatial resolutions of 2.5 m. The polarimetric information can enhance radar capabilities for retrieving the building damage information in more detail(Yamaguchi.2012). Further studies are needed to demonstrate the potential of L-band dual-polarimetry mode ALOS-2/PALSAR-2 for operational earthquake damage analysis. Therefore, in this study, we present original results of earthquake damage assessment in building and urban levels using only the post-event L band dual polarimetric mode ALOS-2/PALSAR-2 imagery.

Outline of research method

On the one hand, radar scattering characteristics of earthquake affected buildings (slightly damaged, totally collapsed and tilt buildings) was initially investigated using the L band dual-polarimetric ALOS-2/PALSAR-2 imagery. Specifically, the characteristic of the polarimetric SAR features, for example, cross-polarization, cross-polarization ratio, were initially investigated to improve the understanding of radar scattering characteristics of earthquake damaged buildings. On the other hand, a control experiment was designed to compare the differences in pixel distribution histogram for polarimetric SAR features in post-event L band dual-polarimetric ALOS-2/PALSAR-2 imagery between the damaged urban areas and undamaged urban areas, the purpose of this experiment is to explore whether the damaged urban areas and the undamaged urban areas are distinguishable in only the post-event ALOS-2/PALSAR-2 imagery.

Main conclusions

In general, three conclusions were achieved as follows: 1) The results demonstrated that it is quite difficult to detect the single building damage from post-event L band dual polarimetric mode ALOS-2/PALSAR-2 imagery, while the detection of urban damage from the post-event L band dual polarimetric mode ALOS-2/PALSAR-2 imagery is possible. 2) Our results also indicated that the polairmetric SAR features and texture feature of SAR image are good indicators for distinguishing the earthquake damage. 3) This study gives us the inspiration to adopt the high-dimensional features based machine learning methods to achieve high-precision earthquake damage assessment.

2.2 Object-Based building damage mapping from Post Event ALOS-2/PALSAR-2 Images

Research background & Purpose

Recently, the exploitation of earthquake damage assessment using only post-event SAR images has gained broad attention and has already demonstrated its preliminary potential for earthquake damage assessment (Dell'Acqua et al., 2011; Li et al., 2012). However, these methods are highly dependent on the fully polarimetric SAR data and/or built-up areas information, the unavailability of fully polarimetric SAR data and/or built-up areas information in real application makes this method less practical. Therefore, a more generalized earthquake damage assessment methodology using only post-event SAR data is highly needed.

Outline of research method

In this study, we selected the 2015 Nepal earthquake as case study to develop our methodology. First, we developed an automatic built-up area extraction method, the built-up area areas were extracted from the speckle divergence of the post-event SAR image. And then the extracted built-up areas were integrated with the building ground truth data to generate the multi-scale object ground truth data by using image split analysis. Furthermore, a comprehensive set of parameters, including 15 polarimetric, 83 texture, and 4 color parameters, were calculated from the post-event ALOS-2/PALSAR-2 image. The parameters information was integrated with the object ground truth data to construct the database for classification. Finally, a Random Forest(RF) machine learning approach was implemented for damage classification. To quantitatively study the contribution of these parameters in damage classification, we introduced the variable importance score as an index to rank the contribution of each parameter. In addition, we also investigated the effect of variable number on the classification accuracy by decreasing the number of input parameters in turn.

Main conclusions

In general, several important finds were achieved in this study as follows: 1) The variable importance ranking indicated that the color features does not contribute as much as those of the polarimetric and texture features for the damage classification. 2)Our results indicate that feature reduction leads to an improved estimation, but also that not all significant features can be fully exploited with one particular segmentation scale. However, the range of potentially useful features for earthquake-induced building damage mapping seems still not fully exploited, other kinds of SAR datasets such as the fully polarimetric SAR dataset should be used to explore the physical scattering mechanism of radar in the earthquake affected built-up areas. 3)In summary, the RF classifier provided relatively high overall accuracies of up to 93% with kappa coefficient of 0.89 when the 180×180 m scale and 15 features are adopted, while the comparative test k-nearest neighbor classifier achieved overall accuracies of up to 91.5% with kappa coefficient of 0.40, which demonstrated that the soft decision of the RF classifier shows a significant improvement in balancing the correct classification.

2.3 A Framework of Rapid Regional Tsunami Damage Recognition from Post-event TerraSAR-X Imagery Using Deep Neural Networks

Research background & Purpose

Recently, the machine learning methods have been widely applied to assess the earthquake damage from the post-event SAR image (Shi et al., 2012). This method does achieve high accuracy, however, the manual and time-consuming feature extraction and selection procedure limits the applicability of this method to meet the needs of rapid disaster emergency response. Considering the limitations of those traditional methods, it is beneficial to develop a framework that can enhance the speed and automation degree of damage recognition.

Outline of research method

In this paper, the 2011 Tohoku earthquake and tsunami in Japan was selected as case study to develop our methodology. In general, a framework of deep learning based rapid regional tsunami damage recognition from post-event SAR imagery is proposed. Specifically, a series of tile based image split analysis was employed to generate the SAR image tiles, following by label generation of image tile based on the building damage ground truth data. Then, a selection algorithm with SqueezeNet network was developed to distinguish between build-up and non-build-up regions swiftly. Finally, a recognition algorithm with modified Wide Residual Network was developed to classify the build-up regions into wash away regions, collapsed regions and slightly damaged regions.

Main conclusions

In general, several important finds were achieved in this study as follows: 1) Our study introduced a deep neural network framework characterized by automatic learning of building damage patterns. A post-event TerraSAR-X Stripmap scene from Tohoku Japan during 2011 Tohoku Tsunami and earthquake was investigated with our deep learning based framework to develop an optimal model for automatic built-up region extraction as well as rapid building damage mapping. Our framework takes around 2 hours to train on a completely new region, and only 2 minutes to predict damage mapping on the whole dataset. 2) Results show that our built-up region selection algorithm based on SqueezeNet network is practical and effective for built-up region extraction by achieving an overall accuracy of 80.4%. 3): Our results also indicate that our recognition algorithm based on modified Wide Residual Networks is effective to distinguish the built-up regions into WAR, CR and SDR with an overall accuracy of 74.8%.

3. Originality of thesis

The main originality of this thesis were; 1) the radar scattering characteristics of earthquake damage were initially investigated using the L band dual-polarimetric ALOS-2/PALSAR-2 image, the potential of polarimetric SAR features in post-event L band dual-polarimetric ALOS-2/PALSAR-2 image for distinguishing the urban damage was also initially investigated. and 2) An earthquake damage assessment method under the framework of random forest using only post-event SAR imagery was developed. and 3) A deep learning based damage assessment framework was firstly proposed to accuracy recognize the damage regions into three levels using only post-event SAR image.

4. References

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論文審査結果の要旨

天候の影響を受けにくく夜間でも撮像できる合成開口レーダ（以下 SAR）は災害等の緊急観測の成功度が高く、詳細な広域被害把握が可能である。しかし、変化抽出法による従来の方法では、同じ撮像条件の災害前後の画像ペアを取得することが必須の条件とされており、災害時の適用性向上の問題となっていた。

そこで、本研究は統計的学習理論を応用し、広域被害把握を可能にする様々な画像の特徴量を検討しながら、「災害後」の画像のみから建物被害を抽出する手法を開発、提案し、その有効性を実証した。

論文は全 6 章よりなる。

第 1 章は序論である。研究背景・目的、論文の構成について説明している。

第 2 章では、既往研究を踏まえ、従来法の利点および課題を整理している。

第 3 章は、多偏波の SAR 画像による地震の建物被害の抽出法を、撮像条件、建物形状、画像特徴量の関連で検討し、3 段階の被害レベルで抽出が可能であることを明らかにした。

第 4 章は、都市域の地震による建物被害抽出法の構築を行っている。具体的には、SAR 画像から得られる後方散乱強度のばらつきに着目した都市指数による都市域抽出と、オブジェクトベース画像処理による被害抽出法を統合して、2015 年ネパール・ゴルカ地震に適用した。特に、機械学習（ランダムフォレスト）による画像解析を導入して総合精度 93。6%の建物被害抽出を達成したことは重要な成果であり、災害後に適切な被害建物のサンプルを取得して学習することで、災害後の画像のみからでも高度な被害把握が可能であることを示した。

第 5 章は、被災後の迅速な被害把握を可能とする深層学習による自動特徴抽出の枠組みを構築、提案している。東日本大震災における津波被害に適用し、建物被害（流失、大破、軽微）の抽出精度が 74。8%という結果を得た。深層学習による方法の利点は、構造化されていないデータに適用することが可能なことであり、仙台平野全体の画像の学習・被害抽出が約 2 時間で完了できるなど、その有効性と迅速性を実証した。

第 6 章は結論である。

以上、本論文は、統計的学習理論を応用して、被災後の SAR 画像のみからの被害抽出法の新しい枠組み構築し、高い精度で広域被害把握が可能であることを明らかにした。従来法の難点を克服した本研究の成果は、災害に見舞われるあらゆる地域での迅速かつ高度な被害把握に大きく貢献できるものである。

よって、本論文は博士（工学）の学位論文として合格と認める。