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SAR Image Change Detection Research: A Review

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Abstract: SAR image change detection technology has always been a research hotspot and difficulty in remote sensing, which has attracted many scholars at home and abroad to conduct in-depth research on it. However, there is still a lack of detection methods with strong generalization, high accuracy, and complete automation. With the development of synthetic aperture radar, the SAR change detection technology system is also constantly updated and evolved. An in-depth analysis of the research status of SAR image change detection technology at home and abroad is carried out to supplement the latest applications of deep learning methods in SAR image change detection methods in recent years. At the same time, focusing on the whole process of SAR image change detection, the theory and methods of SAR image change detection are further categorized and summarized from three aspects: SAR image imaging mechanism, SAR image change detection technology, and accuracy evaluation, and the challenges and future development trend of SAR image change detection are pointed out, to promote the further development of SAR image change detection research.

1. Introduction

The survival of human beings is dependent on the global environment, and global environmental change detection is paramount in the study of global change. Change detection is a technique for determining the various processes of a single object or phenomena based on observations made at different times 0. As an active microwave sensor, synthetic Aperture Radar (SAR) has all-day, all-weather characteristics, is unaffected by extreme weather, can penetrate cloud and rain layers, and covers a large region [2]. As a result, SAR image change detection has a wide range of applications, including agriculture and forest detection, natural catastrophe assessment, medical detection, military operations, etc.

With SAR image change detection garnering scholarly interest, most research reviews have been carried out, focusing on this topic [3] [4] [5] [6] [7]. Based on prior research, this work focuses on the entire process of SAR image change detection methodologies, obstacles, and future development trends of SAR image change detection in conjunction with deep learning.

2. Related work

Synthetic aperture radar (SAR) is a side-looking system. Three main types of information in SAR images: geometric spatial data provided by the images, radar backscatter coefficients provided by the magnitude and phase of pixels, and feature polarized scattering characteristics provided by multi-channel SAR images. The interpretation of SAR images is one of the current hot and challenging issues. The rapid development of synthetic aperture radar and artificial intelligence technology has brought SAR image processing technology changes, which effectively improves semi-automatic and automatic change detection.

3. SAR image change detection

SAR image change detection is the process of identifying the area of surface change by analyzing images taken at different moments at the same location [8]. As shown in Figure 1, the general conventional process of SAR image change detection consists of roughly three steps: (1) Image Preprocessing, (2) Change Detection, (3) Performance Evaluation.

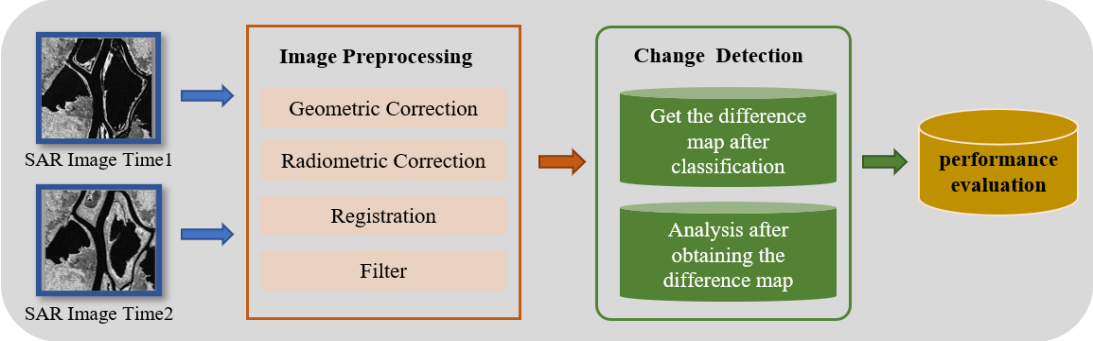
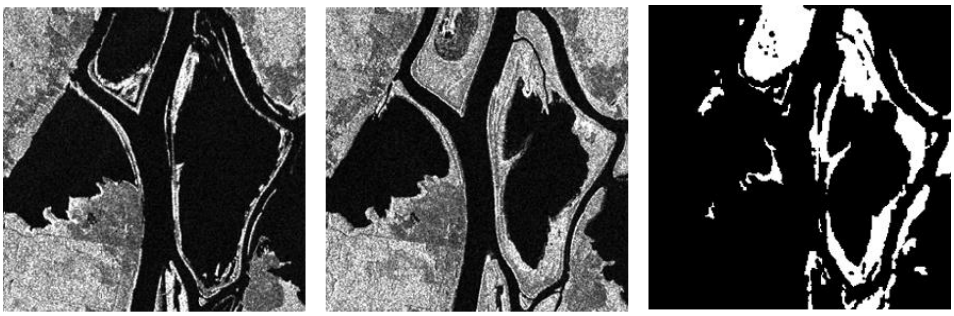


Figure 1: The process of SAR image change detection consists of roughly three steps

3.1. SAR image dataset and preprocessing

3.1.1. Change detection dataset

The SAR image change detection datasets are all real-time multi-temporal SAR images, containing two registered SAR images of different moments and a ground-truth image, as shown in Figure 2.



Ottawa199703 Ottawa199707 Ottawa_gt

Figure 2: OTTAWA SAR Image dataset: This dataset was taken by the RADARSAT-SAR satellite in March 1997 and July 1997, with a 12 m resolution and a 290*350 image size. The dataset illustrates the seasonal variance of river channels in the Ottawa region of Canada. The map on the right depicts the ground-truth image.

3.1.2. Image Preprocessing

The information acquisition of a SAR system is affected by factors such as sensor height and attitude angle. So, before the change detection of SAR images, a reasonable and practical image pre-processing process is essential, primarily geometric correction, radiation correction, and image denoising, Etc. The deep learning method reduces the impact of image denoising on change detection accuracy.

1) Geometric Correction

Geometric correction is the technique of correcting or reducing the deformation produced by the changing position of the SAR sensor during SAR imagin. In practical geometric correction, the SAR image of one time is often chosen first for absolute geometric correction, followed by the SAR image of another time image for relative geometric correction.

2) Radiometric Correction

Radiation correction can be defined as the process of correcting or removing image distortion caused by radiation differences in SAR imaging. In practical applications, the commonly used method is relative radiation correction.

3) Image Denoising

As a result of the coherent imaging mechanism, SAR images are accompanied by speckle noise, unlike optical images. The more multiplicative severe coherent speckle will be attached to the SAR image in the form of "point" noise, which affects the accurate feature information and difficulties the change detection of SAR images [9]. Traditional SAR image denoising algorithms include Lee filter, Frost filter, Map filter, etc. In recent years, deep learning has recently become more popular. The data-driven nature of this method provides better flexibility and the ability to capture various features observed in SAR images.

3.2. SAR Image Change Detection Technology

3.2.1. Change detection method

There are two sorts of regularly employed detection methods in change detection: (1) Classification first and then detection, that is, first classify the two SAR images separately, then compare the classification results, and then get the change information [10] [11]. (2) First, the different images are produced, and then they are evaluated to obtain the final change data. The premise is straightforward, with enough room for investigation, and is currently the mainstream research.

3.2.2. SAR image change detection technology

Based on the review of earlier work [3] [4] [5] [6] [7], the paper makes further additions and improvements to the development of SAR image change detection technology. Making a general view of the development of SAR change detection, The SAR image change detection technology consists primarily of the embryonic development, emergence, and climax periods [12].

- The first stage (1980s-1990s): the embryonic period

Rignot [13], Vilasenor [14], and others initiated pioneering exploratory research while SAR pictures were still unipolar and low to medium resolution.

- The second stage (1920s- the early 2000s): the development period

Initially, many researchers did not account for the multiplicative coherent speckle noise of SAR images and utilized the same algorithm as that for optical images. Through a comprehensive analysis of SAR images, the ratio method, mean-ratio algorithm, and log-ratio algorithm were

developed to successfully reduce multiplicative coherent speckle noise and improve the resilience of the difference image. The majority of SAR change detection methods, however, are now low to medium-resolution, pixel-level, single-polarization SAR picture change detection.

- The third stage (2000-2012): the emergence period

Gradually, machine learning algorithms are introduced to the field of SAR image change detection. ZHENG [14] incorporated the K-Means mechanism to enhance the simplicity of detection. Subsequently, machine learning algorithms such as fuzzy clustering and C-means have laid the foundation for semi-automated and automated change detection of SAR images.

- The fourth stage (2012-present): the climax period

Other novel remote sensing methods for space-to-earth observation have been developed over the past decade with the advancement of hardware and software, while neural network models have ushered in a new era in SAR image change detection.

With the rapid development of convolutional neural networks (CNN), the method has been gradually introduced into the field of change detection. Due to the SAR image characteristics, the network is later required to have a stronger multi-scale representation capability. Variable residual networks and multi-scale convolutional networks [16] effectively utilize multi-scale information and are therefore quite popular among researchers. End-to-end change detection based research has emerged [17] [18] [19] [20]. In the recent two years, numerous researchers have combined and expanded the attention mechanism to propose a dual-attention mechanism [21] [22] [23], which combines spatial attention and channel attention to increase the model's ability to perceive changes and its robustness against artifacts. With the development of various time-series data sources, multi-time-series SAR image change detection has become a trendy hotspot in change detection, and the computational burden has increased accordingly, so lightweight neural networks [24] are being gradually incorporated into SAR image change detection.

Deep learning-based SAR image change detection significantly improves the generalization ability and robustness of change detection, but the unique characteristics of SAR images relative to other remote sensing images limit the scalability of deep learning's application to SAR image change detection.

3.3. Performance Evaluation

Accuracy evaluation in the field of remote sensing involves qualitative and quantitative assessment, which is a summary review of the entire process of change detection, and accuracy evaluation can be used to illustrate the performance of the change detection model [25].

Qualitative evaluation criteria are used to detect model performance by visual, abbreviated observation of changes. The common methods for quantitative evaluation criteria are mainly based on the error matrix and Kappa coefficient.

4. Challenges and perspective

Existing theoretical methods based on deep learning have not yet reached fully automated and highly accurate change detection. Consequently, SAR image change detection still faces obstacles and has development potential.

- Data source: SAR data has lower resolution and lower signal-to-noise ratio (SNR) characteristics and the amplitude information contained in SAR images is far from the imaging level of optical data. Multiple remote sensing data can be combined, such as using optical images to assist SAR images, and the advantages complement each other for the change detection of SAR images.
- Preprocessing: The scatter phenomenon has been a significant obstacle to SAR image

interpretation, and deep neural networks can bring a novel solution to this long-standing issue. However, the majority of deep learning-based denoising techniques focus on intensity images. Multi-channel SAR images create additional hurdles in polarized and interferometric SAR. SAR images that may be used for extended time sequences with frequent revisit durations and descattered Spatio-temporal correlation qualities allow for effective scatter suppression via Spatio-temporal filtering. The construction of generalized networks capable of managing time stacks of varying sizes is also of significant importance for processing SAR images with long time series.

● Change detection techniques: Various deep learning-based SAR image change detection methods have their own advantages and disadvantages. But generally, generalization ability is weak, then there is no one efficient method that can be applied to all scenes. Secondly, feature extraction and image segmentation techniques are subject to SAR image feature correlation and texture features and other factors images. As a result, the limitation of deep learning methods is their lack of interpretability: the highly nonlinear nature of the network and its numerous parameters. A way to improve deep learning methods and increase interpretability is to combine them with more traditional processing techniques, such as PATCH-based methods.

References

[1] SINGH A. Review article digital change detection techniques using remotely-sensed data [J]. International journal of remote sensing, 1989, 10(6): 989-1003.

[2] WHITE R G. Change detection in SAR imagery [J]. International Journal of remote sensing, 1991, 12(2): 339-360.

[3] HACHICHA S, CHAABANE F. On the SAR change detection review and optimal decision [J]. International Journal of Remote Sensing, 2014, 35(5): 1693-1714.

[4] LIU MingXu, Zhang Yonghong. Review of SAR Image Change Detection [J]. Geospatial Information, 2014, 12(03): 36-40+6.

[5] Chen FuLong, Zhang Hong, Wang Chao. The Art in SAR Chang Detection-A Systematic Review [J]. Remote Sensing Technology and Application, 2007, 22(1): 109–115.

[6] Yang Jing,Shen Chen,Wang XianBin. A Review of SAR Image Change Detection Technology Research [J]. China Water Transport, 2011(1): 109–111.

[7] Wu Tao, Chen Xi, Niu Lei, et al. Latest Development of Research on Unsupervised Change Detectionin SAR Images [J]. Remote Sensing Information, 2013(1): 110–118.

[8] Chen BeiBei. SAR Images Change Detection Based on Deep Learning [D]. Xi'an: XIDIAN UNIVERSITY, 2020.

[9] Wu Fei. SAR Images Change Detection Based on Generative Adversarial Network and Non-Local Neural Network [D]. Xi'an: XIDIAN UNIVERSITY, 2019.

[10] KRIZHEVSKY A, SUTSKEVER I, HINTON G E. Imagenet classification with deep convolutional neural networks [J]. Advances in neural information processing systems, 2012, 25.

[11] ZHANG Xiaoyu, ZHAO Fengjun, LI Ling. Change Detection in SAR Image Based on Multi-Channel Features [J]. Radar Science and Technology, 2017, 15(05): 509-518.

[12] REN Qiuru, YANG Wenzhong, WANG Chuanjian, WEI Wenyu, QIAN Yunyun. Review of remote sensing image change detection [J]. Journal of computer Application, 2021, 41(08): 2294-2305.

[13] RIGNOT E J M, VAN ZYL J J. Change detection techniques for ERS-1 SAR data [J]. IEEE Transactions on Geoscience and Remote sensing, 1993, 31(4): 896-906,

[14] VILLASENORENSOR J D, FLATLAND D R, HINZMAN L D. Change detection on Alaska's North Slope using repeat-pass ERS-1 SAR images [J]. IEEE Transactions on Geoscience and Remote Sensing, 1993, 31(1): 227-236.

[15] YAOGUO ZHENG, XIANGRONG ZHANG, BIAO HOU, et al. Using combined difference image and k-means clustering for SAR image change detection [J]. IEEE Geoscience and Remote Sensing Letters, 2013, 11(3): 691-695.

[16] WANG J, GAO F, DONG J. Change detection from SAR images based on deformable residual convolutional neural networks[C]. Proceedings of the 2nd ACM International Conference on Multimedia in Asia. 2021: 1-7.

[17] GONG M, YANG H, ZHANG P. Feature learning and change feature classification based on deep learning for ternary change detection in SAR images [J]. ISPRS Journal of Photogrammetry and Remote Sensing, 2017, 129: 212-225.

[18] MOU L, BRUZZONE L, ZHU XX. Learning spectral-spatial-temporal features via a recurrent convolutional neural network for change detection in multispectral imagery [J]. IEEE Transactions on Geoscience and Remote Sensing, 2018, 57(2): 924-935.

[19] JI Shunping, TIAN Siqi, ZHANG Chi. Urban Land Cover Classification and Change Detection Using Fully Atrous

Convolutional Neural Network [J]. Geomatics and Information Science of Wuhan University, 2020, 45(2): 233-241.
[20] GONG M, ZHAO J, LIU J, et al. Change detection in synthetic aperture radar images based on deep neural networks [J]. IEEE transactions on neural networks and learning systems, 2015, 27(1): 125-138.
[21] CHEN L, ZHANG H, XIAO J, et al. SCA-CNN: Spatial and channel-wise attention in convolutional networks for image captioning [C]. Proceedings of the IEEE conference on computer vision and pattern recognition. 2017: 5659-5667.
[22] WOO S, PARK J, LEE J Y, et al. CBAM: Convolutional block attention module [C]. Proceedings of the European conference on computer vision (ECCV). 2018: 3-19.
[23] FU J, LIU J, TIAN H, et al. Dual attention network for scene segmentation [C]. Proceedings of the IEEE/CVF conference on computer vision and pattern recognition. 2019: 3146-3154.
[24] WANG R, DING F, JIAO L, et al. Lightweight convolutional neural network for bitemporal SAR image change detection [J]. Journal of Applied Remote Sensing, 2020, 14(3): 036501.
[25] OLOFSSON P, FOODY G M, HEROLD M, et al. Good practices for estimating area and assessing accuracy of land change [J]. Remote sensing of Environment, 2014, 148: 42-57.