Monitoring of rice lodging using Sentinel-1 data

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Abstract. Synthetic Aperture Radar (SAR) can monitor rice regardless of time and weather condition, and the ability of crop lodge monitoring has been demonstrated by previous studies. However, there have no study about monitoring of rice lodging using satellite-based SAR. In this study, we extracted backscatter coefficient (BC) and H/A/Alpha polarimetric parameters from dual-polarized Sentinel-1 SAR data, and a lodging sensitivity factor γ was constructed for selecting optimal radar feature parameter (ORFP) which is highly sensitivity to lodging rice. Then, the decision tree classification method was used with multiple ORFPs to classify the healthy and lodging rice plots. We firstly acquired shape of rice region using Sentinel-2 image and Maximum likelihood classification method for eliminating the influence of other features before classification of lodging rice. The result showed that the overall accuracy of 87.18% is achieved with the combination of ORFPs and decision tree.

1. Introduction

Lodging, a common disaster in rice cultivated region, is mainly induced by strong winds, heavy rainfall and pests. The rice stem will bend after lodging, and the magnitude of rice production will decrease as the canopy photosynthesis is disrupted due to ‘self-shading’. Paddy rice will be threatened by strong wind and heavy rain on a large scale when typhoon crosses the region. It is important to determine the range and location of the lodged rice plots quickly and accurately after typhoon passes through the rice cultivated region because grain and root will rot after long-time soaking in the flood.

The traditional method of monitoring lodged rice is visual observation on site and assessment. It was high-cost and cannot meet the requirement of monitoring synchronization to large scale lodging rice plot caused by typhoon. Remote sensing technology (RST) provides a cost-effective and multi-scale method for monitoring lodging crops [1]. Until now, the studies of lodging rice monitoring using RST mainly focused on visible and infrared by unmanned aerial vehicles (UAVs). Hyperspectral data was confirmed that it has ability to distinguish the lodged and healthy rice based on principle component analysis (PCA) and probabilistic neural network (PNN) [2]. 96.17% classification result of local-scale lodging rice was acquired by combination spectral indices, texture information and...
digital surface model (DSM) collected from UAV images [3]. The difference of lodging and healthy rice in temperature, color and texture extracted from UAV visible and thermal infrared images was analyzed, and a model was constructed to recognize the lodged rice based on support vector machine (SVM) and particle swarm optimization (PSO) [4]. However, the monitoring coverage area of image acquired by UAV is small. It is not suitable for large-scale periodic observation of rice lodging. Satellite-based optical has wide-coverage, but cannot acquire data timely due to the limitation of cloud and rain [5].

Satellite-based SAR has monitoring advantage of all-weather, all-day and wide-coverage. Scholars have demonstrated that the microwave emitted by SAR is sensitive to structure of lodging crops in previous studies. The lodging wheat, beet and sugarcane were monitored using full polarization data of Radarsat-2, and found that multi polarimetric parameters are highly sensitive to lodging wheat and sugarcane [1][6][7]. optimal polarimeter indexes were screened to lodging corn, and a model was constructed to classify corn with different lodging degree. Multiple polarimetric parameters extracted from Radarsat-2 and Sentinel-1 were analyzed, and wheat was classified with different crop inclination angle (CIA) [8][9].

In this study, we used open source and free Sentinel-1/2 data, and explored the sensitivity of polarimetric parameters extracted from Sentinel-1 to lodging rice. The ORFP which was screened by γ and discrimination analysis was used to classify the healthy and lodging rice, and the classification accuracy was validated by confusion matrix.

2. Study area and data

2.1 Study area
The study area is located in the Qindeli Farm (Fig.1), which belongs to Tongjiang city, Heilongjiang Province, China. The geographic coordinates of the center are 47°51′31″N, 133°7′32″E. The total cultivated area of farm is about 52800 hectares, of which rice planting area accounts for more than 80% of the total cultivated area.

The rice growth period of the study area lasts nearly five months, from beginning of May to the end of September. The study area was invaded by typhoon Lingling, accompanied by heavy rainfall that lasted for two days (September 7 and 8, 2019). A large of mature rice field lodged. The location of sample fields is shown in Fig.1.

Fig.1. The study area (left) and location of the sample fields overlaid on a Sentinel-2 image (right) acquired on 17 Sep 2019. Yellow solid circle is healthy rice plot and red is lodge plot.

2.2 Experiment data
In order to explore the sensitivity of different SAR features to the lodging rice, two Sentinel-1B dual-polarized SAR images (August 26 and September 19, 2019) before and after the typhoon...
‘Lingling’ crossing were selected. The radar BC (VV and VH) and H/A/Alpha parameters were extracted and analyzed.

The spatial resolution of Sentinel-1 is low compared to Sentinel-2, and there have speckle noise and detailed features broken in SAR image as special imaging mechanism. In this context, we extracted shape of rice using Sentinel-2 image of high spatial resolution. The pan Pleiades of 0.5m spatial resolution was selected as validation data of classification result (Table1).

| Satellite   | Sentinel-2B | Pleiades |
|-------------|-------------|----------|
| Spatial Resolution | 10m B2 Blue | 0.5m Pan 470–830nm |
| Spectrum range      | B3 Green    | B4 Red   |
| Swath width         | 290Km       | 20Km     |
| Revisit             | 5d          | 1d       |
| Acquisition         | 17 Sep.2019 | 14 Sep.2019 |

3. Methodology

3.1 Pre-processing of SAR image

We extracted the BC and H/A/Alpha parameters from two Sentinel-1B images using SNAP 7.0 and PolSARpro 6.0, respectively. The SLC data was processed in SNAP including orbit correction, thermal noise removing, multilooking, radiometric calibration, speckle filter and Terrain Correction, and the BC images of VV and VH were generated. The image of VV+VH, VV-VH, VH/VV were acquired by band math operator.

For H/A/Alpha polarization decomposition, we firstly extracted IW1 subswath and C2 matrix in PolSARpro 6.0. After multilooking, geocoding and H/A/Alpha decomposition, a total of five polarimetric parameters were generated including Alpha, Entropy, Anisotropy, Span and Shannon. These parameters were calculated based on C2 matrix and eigenvalues and the formula as following:

\[
\text{Alpha} = \frac{1}{\lambda_1 + \lambda_2} \sum_{i=1}^{2} \lambda_i \alpha_i
\]

\[
\text{Anisotropy} = \frac{\lambda_1 - \lambda_2}{\lambda_1 + \lambda_2}
\]

\[
\text{Entropy} = -\sum_{i=1}^{2} P_i \log_2(P_i)
\]

\[
\text{Shannon} = 2 \log(\frac{\pi e \text{Tr}(C_2)}{2}) + \log(4 \frac{\det(C_2)}{\text{Tr}(C_2)^2})
\]

\[
\text{Span} = |C_{11}|^2 + 2|C_{12}|^2 + |C_{22}|^2
\]

3.2 Screening of ORFP

We selected ten healthy (H1-H10) and ten lodge (L1-L10) sample plots based on Pleiades image. Then, we counted the mean value of each sample plots so that eliminating the inhomogeneity of SAR. In order to select ORFP, a lodging sensitivity factor \(\gamma\) was constructed to screen out parameters that are insensitivity to lodging rice.

\[
\gamma = \frac{LB_{av} - LA_{av}}{LB_{av} + LA_{av}} - 1.5 \times \frac{HB_{av} - HA_{av}}{HB_{av} + HA_{av}}
\]

where \(LB_{av}\) denotes mean value of all lodged plots before lodging, and \(LA_{av}\) is mean value of all
lodged plots after lodging. \( HB_{av} \) and \( HA_{av} \) are mean value corresponding to healthy plots.

The variation of the parameter of lodging plots before and after lodging is much greater that that of the corresponding the healthy rice when \( \gamma \) is greater than 0. Therefore, we define the parameter which satisfy the condition of \( \gamma \) greater than 0 has sufficient sensitivity to lodging rice.

In order to achieve high accuracy classification result of lodging and healthy rice plots, the parameters filter by \( \gamma \) need to be further explored whether have strong ability to distinguish between the lodging and healthy rice. We performed discrimination analysis by observing the boxplot, and selected the parameters that can be used decision tree classification as ORFP.

3.3 Classification of lodging and healthy rice
Although rice is the main crop in the study aera, buildings, water bodies, roads, woods and other crop will decrease the decision tree classification accuracy of lodging and healthy rice. We extracted shape of rice region using Maximum likelihood (ML) method and Sentinel-2 image to reduce interference for decision tree.

Finally, based on the ORFP image selected by screening model and shape of rice region, a cropped image of the ORFP rice area is generated using the mask function of ArcMap. At the same time, we determined the level of ORFP in the decision tree according to the magnitude of \( \gamma \). Each level of decision tree only gets two types of lodging and healthy rice as the other features were removed in advance. We construct sub-branch for each layer of lodging rice category and continue to classify until the end of the last layer. The multi healthy rice categories were merged into one, and the final result of ORFP decision tree classification was obtained.

4. Results and analysis

4.1 Screening Optimal radar feature parameter
We can clearly find that VV, VH, VV+VH, VV-VH, Shannon and Span satisfy the screening conditions of \( \gamma \). The reason why VV is sensitive to lodging rice is the weakening of the stalk attenuation to V polar as the vertical structure of the rice stalk was destroyed [10], and the enhancement of multiple scatter after lodging is main reason for the sensitivity of VH to lodging rice [1]. Alpha, Anisotropy and Entropy reflect different scatter mechanisms, and had high sensitivity to lodging crop in previous studies. However, Alpha, Anisotropy and Entropy are not sensitivity to lodging rice in this study. This situation may be caused by the lack of the polarization information of dual-polarized data compared to fully polarized data.

| parameter | \( LB_{av} \) | \( LA_{av} \) | \( HB_{av} \) | \( HA_{av} \) | \( \gamma \) |
|-----------|---------------|---------------|---------------|---------------|---------|
| VV        | -12.25        | -11.1         | -11.66        | -12.27        | 0.011   |
| VH        | -17.13        | -15.52        | -16.91        | -16.86        | 0.047   |
| VV+VH     | -29.37        | -26.82        | -28.56        | -29.12        | 0.031   |
| VV-VH     | 5.18          | 4.43          | 5.06          | 4.59          | 0.005   |
| VH/VV     | 1.41          | 1.40          | 1.46          | 1.38          | -0.04   |
| Alpha     | 0.83          | 0.92          | 0.85          | 0.94          | -0.019  |
| Anisotropy| 0.49          | 0.47          | 0.51          | 0.49          | -0.011  |
| Entropy   | 0.81          | 0.83          | 0.79          | 0.81          | -0.006  |
| Shannon   | 0.48          | 0.67          | 0.53          | 0.51          | 0.125   |
| Span      | -10.88        | -9.63         | -10.37        | -10.86        | 0.026   |

Fig.2 shows the polarimetric parameter values of healthy and lodging rice plots after lodging. We can find that the values of healthy and lodging box for VV-VH are too close. The maximum value of healthy box is close to median value of lodging box for VV, and Span has a similar situation. The other parameters have enough discrimination, and VH is complete distinction. Therefore, we selected VH, VV+VH and Shannon as ORFP for decision tree classification.
Fig. 2 Box plots presenting the polarimetric feature values of healthy and lodging sample plots after lodging. The lodged boxplots are in red color and the healthy boxplots are in blue color.

4.2 Decision tree classification and validation

We constructed a decision tree based on ORFP and rule mentioned in section 3.3. The classification process was performed in ENVI 5.3, and three Healthy rice categories were combined using combine classes operator (Fig. 3(b)). The validation of the classification results adopts the confusion matrix method, and the overall accuracy of result is 87.18%.

Fig. 3 Decision tree classification result (a) and the structure of decision tree (b).

The factors of decrease the classification accuracy have two points: (i) The north-south span of the study area is about 20Km, and the east-west span is about 10Km. The large spatial scale results in the simultaneous existence of multiple rice varieties. The difference in biological characteristics of rice are shown in SAR images as regional difference of BC; (ii) The spatial resolution of Sentinel-1 is low. One pixel is the result of the common scattering of multiple rice plants.
5. Conclusions
In this study, we analyzed the sensitivity of backscatter coefficient and H/A/Alpha decomposition parameters extracted from dual-polarized Sentinel-1 data to lodging rice, and constructed a lodging sensitivity factor $\gamma$ to screen the optimal radar feature parameters for decision tree classification. VH, VV+VH and Shannon were selected as ORFP after screening, and the overall classification accuracy reached 87.18%.

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