An SAR De-noising Algorithm Based on Brainstorming Optimization Strategy in NSCT Domain

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Abstract — Beside additive noise, there is also sparkle multiplicative noise in the Synthetic Aperture Radar (SAR) image, which will greatly reduce the quality of SAR images. For this problem, we propose a new SAR image de-noising algorithm in NSCT domain based on brainstorming optimization strategy. In this algorithm, we first do a NSCT transformation for the SAR image noise, then obtain the best de-noising threshold by the PSNR (Peak Signal to Noise Ratio) optimization through the brainstorming optimization strategy, and finally get the enhanced image through the image histogram equalization processing based on convolution neural network.

Keywords - Optimization; NSCT; SAR; Convolution neural network; Image enhance; MATLAB

I. INTRODUCTION

Synthetic aperture radar technology is a kind of all-weather microwave remote sensing imaging technology, which has many advantages of high resolution, strong penetrability, etc [1]. But in the actual process of SAR imaging, in addition to the influence of the additive noise, its resolution performance will also be affected by the random phase of sparkle noise, which will influence the quality of the SAR image seriously [2-3]. So the research of SAR image de-noising is the most important step in the SAR image processing.

In the recent year, there are many research results about SAR image de-noising. In the year of 1985, Professor CRIMMINS had proposed a method of geometry filtering, but the calculation of this method is very large, which is very difficult to use in application [4]. In the 1990s, Lee had proposed a method of spatial filtering method which is based on local statistical characteristics [5]. In the year of 1998, Professor Jose had proposed a SAR image restoration algorithm based on BAYES theorem [6]. Professor Frost had proposed a method of adaptive filter based on coherent lines point noise [7]. Professor Donoho had proposed wavelet threshold de-noising algorithm [8], including the hard threshold and soft threshold.

Most traditional SAR image de-noising algorithms can only reduce a part of the SAR image noise, for the additive noise or multiplicative noise. On the other hand, most of the SAR image de-noising algorithms is based on wavelet domain filtering processing, which is not well done in the kind of high singular signal and affect the continuity of SAR image edge.

So in this paper, the author will propose a new SAR image de-noising algorithm in NSCT domain based on brainstorming optimization strategy, the SAR image can hold good directivity, anisotropy and translation invariance in NSCT domain, we can get the de-noising threshold in NSCT domain through brainstorming optimization strategy, and enhance the SAR image by convolution neural network finally.

II. THE NOISE MODEL OF SAR IMAGE

The SAR noise model include the additive noise and sparkle noise. The additive noise is not related to the SAR image. SAR image with additive noise can be expressed in the following formula:

$$I_0 = I_n + n_a$$

Where $n_a$ is the additive noise, which is a random process of zeros mean Gauss independent identically distributed random process, $I_0$ is the SAR image with additive noise.

The sparkle noise is refers to the synthesis of echo amplitude in the target reflected real return on the basis of the amplitude increases or decreases. The sparkle noise of SAR image can be expressed as:

$$I_0 = I_n \times F$$

Where $F$ is the intensity of sparkle noise, which Obey the probability density function gamma distribution of zeros means and $1/L$ variance. The formula is:

$$P(F) = \frac{1}{\Gamma(L)} L^{L-1} e^{-L/F}$$

Where $\Gamma(\bullet)$ is the gamma function, $L$ is the intensity of sparkle noise. The formula 3 can be transformed to the following formula 4:

$$I_0 = \ln(I_n) + \ln(F) = I_n + \tilde{F}$$

Based on the formula 1~3, we can get the formula of probability density function of sparkle noise:

$$P(F) = \frac{1}{\Gamma(L)} L^{L-1} e^{-L/F}$$

Where $\tilde{F}$ is the intensity of sparkle noise.
So, the probability density function of sparkle noise is similar to obey a \( \frac{1}{2L} \) mean, \( \frac{1}{L} \) variance gauss distribution. As a result, the problem of sparkle noise filtering can be converted into the problem of additive gauss noise filtering.

III. SAR DE-NOISING BASED ON BSO

A. The Tilt Angle

NSCT transformation is proposed on the basis of CONTOURLET transform, which not only has the characteristics of multi-resolution, localization and direction, and overcome the disadvantage of the CONTOURLET transform[10]. The NSCT transform on the structure can be divided into the non sampling pyramid filter group (NSPFB) and non sampling direction filter group (NSDFB).

The NSPFB is designed by atrous algorithm, which can achieve perfect reconstruction of dual channel filter. Its structure is as follows figure:

![Fig.(1). The Structure Of NSPFB](image)

SAR image decomposition can be realized through the limited filter interpolation by atrous algorithm, and get a low frequency coefficient and high frequency coefficient which has the same size as the original SAR image, namely:

\[
f(m,n) = f_j(m,n) + \sum_{j=1}^{J} \omega_j(m,n)
\]

\[
\omega_j(m,n) = f_j(m,n) - f_{j-1}(m,n)
\]

Where \( f_j(m,n) \) is the low frequency part of the original SAR image; \( \omega_j(m,n) \) is the high frequency part of the original SAR image in the scale \( j \). We can get multiple directions information by NSPFB decomposition.

The structure of NSDFB is a dual channel fan shaped filter(show in figure2). In order to obtain higher precision decomposition, The first level of NSDFB is the direction filter set, which has better selection of direction and frequency. The second level of NSDFB is the blossom plum sampling matrix[11,12], the basic structure of blossom plum sampling matrix is \([1,1,1,1],[1,1,1,1]\) respectively. The number of samples is half of the original after sampling.

![Fig.(2). The Structure Of NSDFB](image)

In figure2, the NSDFB structure shows that the interpolation filter have a chessboard in the frequency domain, the former of the filter is combined to realize frequency domain decomposition in four directions. Through the filter set, the frequency domain can be decomposed into multiple wedge frequency region.

Here, assume that the original SAR images is \( I(x,y) \), the images of NSCT decomposition process can be represented by the following formula:

\[
I(x,y)_{NSCT} = a_j + \sum_{j=1}^{J} \sum_{k=1}^{l} b_{j,k}
\]

Where \( a_j \) is the low frequency sub-band, \( b_{j,k} \) is the high frequency sub-band in \( j \) scale and \( k \) direction, \( J \) is the decomposition level of NSPFB, \( l_j \) is the decomposition level of NSDFB in level \( j \). The low frequency part of NSPFB decomposition multi-scale decomposition can get a bizarre point, capture the image contour.

To sum up, The NSCT transformation can realize SAR image multiple directions and scales analysis through NSDFB filtering and NSPFB filtering.

B. BSO STRATEGY AND IMPROVEMENT

The traditional intelligent algorithms are almost based on animals swarm behavior, there are many disadvantages among them. While the brainstorming optimization is a new kind of intelligent algorithm based on human creative[11,12,13,14].

The brainstorming optimization algorithm is according to the following steps:

First, generating the individuals with the \( n \) population size, dividing the \( n \) individuals into \( m \) categories by k means clustering algorithm, and select an optimal individual as a central body respectively.

Second, selecting a central body from the \( m \) categories, and determine whether the central body is replaced by other random individuals by the probability.

Third, individual updating through the specific method. The methods mainly include the following four patterns:

1) Choosing a category randomly and generating a new individual by adding random disturbance to the class center.

2) Choosing a category and then selecting an individual randomly. And adding the random disturbance to new individual.
3) Choosing two categories randomly, incorporating their center together. Generating two new individuals by adding random disturbance to them.

4) Choosing two categories randomly, selecting an individual from each category, then incorporating them together and adding random disturbance to generate a new individual.

Here, the formula of incorporating can be expressed as the following:

\[ P_{\text{new}} = \alpha P_1 + (1 - \alpha) P_2 \]  

(9)

Populations updating is according to the following iteration rules:

\[ P_{\text{new},d} = P_{\text{old},d} + \xi \times \gamma(k, \sigma) \]  

(10)

The range of \( \alpha \) is from 0 to 1, \( \xi(k, \sigma) \) is a gauss random function. In addition:

\[ \xi = \frac{\epsilon}{1 + e^{-\left(\frac{x - T}{T}\right)^2}} \]  

(11)

where \( T \) is the max number of iterations, \( t \) is the current iteration, \( \epsilon \) is a random data with the range of 0~1.

But in reality, the creation process of the brainstorming is implemented through the random noise in formula 10. While the method of formula 10 can not search the best value in the k scale and j direction, the energy in different direction of SAR image in NSCT domain can calculated by the following formula:

\[ E_{I} = \sum_{x,y} |I_{x,y}|^2 \]  

(12)

STEP 2: Direction energy calculation

Because the NSCT transformation is a linear process, So the energy in different direction of SAR image in NSCT domain can calculated by the following formula:

\[ E_{I} = \sum_{x,y} |I_{x,y}|^2 \]  

(13)

When the energy is large, the contour details information in the k scale and j direction is more, and vice versa.

STEP 3: Soft threshold calculation adaptive de-noising

When a particular direction image contour detail information is very more, it should be set a smaller threshold; On the other hand, When a particular direction image contour detail information is very less, it should be set a larger threshold; According to this problem, the proposed algorithm of the paper has proposed a initial threshold value[15].

\[ T_{0} = \sqrt{2 \ln(N)} \]  

(14)

where \( N \) is the image pixel points.

For different scale, the threshold can be calculated by the following formula:

\[ T_{0,k} = K_{BSO} \times \sqrt{\frac{1}{\frac{1}{4} \sum_{j} E_{I}'_{I}}} \]  

(15)

Where \( K_{BSO} \) is the threshold adjust coefficient based on the brainstorming optimization strategy.

Based on the formula 16, the process of SAR image denoising can be defined as:

\[ I'_{I,j,k} = \begin{cases} I_{I,j,k}, I_{I,j,k} \geq T_{0,k} \\ 0, \quad I_{I,j,k} < T_{0,k} \end{cases} \]  

(16)

where F is the sparkle noise, n is the additive noise. After the log calculation, we can get that:

\[ I_{I} = \ln(I_{I}) \]  

(17)

\[ = \ln(F \times I_{I} + n) \]  

(18)

\[ = \ln(F) + \ln(I_{I}) \]  

(19)

Through the first step, we can get the SAR image noise formula 12 and the corresponding logarithmic domain image 12 formula.

And then do the NSCT transformation:

\[ \begin{cases} I_{I,j,k} = a_{j} + \sum_{l=1}^{J} \sum_{k=1}^{S_{l}} d_{l,k} \times b_{l,k} \end{cases} \]  

(20)

STEP 2: Direction energy calculation

Because the NSCT transformation is a linear process, So the energy in different direction of SAR image in NSCT domain can calculated by the following formula:

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(22)

where \( N \) is the image pixel points.

For different scale, the threshold can be calculated by the following formula:

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(23)

Where \( K_{BSO} \) is the threshold adjust coefficient based on the brainstorming optimization strategy.

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\[ I'_{I,j,k} = \begin{cases} I_{I,j,k}, I_{I,j,k} \geq T_{0,k} \\ 0, \quad I_{I,j,k} < T_{0,k} \end{cases} \]  

(24)
image filtering. For SAR image de-noising in logarithm
domain, also use the above formula to calculate.

STEP 4: NSCT inverse transformation and image fusion

In this step, the algorithm will calculate the NSCT inverse transformation firstly, and then calculate the exp operation to obtain the SAR image. At last, the algorithm will calculate the NSCT transformation. At this time, we can get the NSCT domain coefficients without additive noise and multiplicative noise respectively. Finally, we will fusion these two groups of NSCT coefficients, for low frequency parts, the fusion rules is that:

$$I_{new,j,k} = \frac{1}{\sigma_A + \sigma_B} (\sigma_A \times I_{1L,j,k} + \sigma_B \times I_{2L,j,k})$$  \hspace{1cm} (20)

Where $I_{1L,j,k}$ is the low frequency in NSCT domain after de-noising the additive noise. $I_{2L,j,k}$ is the is the low frequency in NSCT domain after de-noising the sparkle noise.

For the high frequency, the fusion rules is that:

$$I_{new,j,k} = \begin{cases} I'_{1L,j,k} & I'_{1L,j,k} \geq I'_{2L,j,k} \\ I'_{2L,j,k} & I'_{2L,j,k} < I'_{1L,j,k} \end{cases}$$  \hspace{1cm} (21)

At last, do the NSCT inverse transformation to obtain the SAR image after filtering.

STEP 5: Threshold optimization based on brainstorm

In step 3, the calculation of parameters $K_{BSO}$ has a very profound impact on the performance of filtering. This algorithm will obtain the best parameters $K_{BSO}$ through the brainstorming optimization. The process is as follows:

First, determine the objective function:

$$\text{fitness} = 10 \log_{10} \left( \frac{L}{\sum_{i,j} (l(i,j) - I_{o}(i,j))^2} \right)$$  \hspace{1cm} (22)

Where $M$ is the row number of SAR image, $N$ is the column number of SAR image, $L$ is max value of pixel. The formula 22 is the object function of GA algorithm, when the function reach the max value, parameter $K_{bs}$ is the optimal value, and the de-noising image will be infinite close to the initial image, at this time, formula 22 will tend to infinit.

Generating n individuals as the solution of $K_{BSO}$. The algorithm will obtain the ideal SAR image through STEP1~STEP4.

The above algorithm flow chart shows the whole process of the algorithm realization.

IV. SAR IMAGE ENHANCE BASED ON CNN

After de-noising, the edge information of SAR image may become fuzzy. In order to improve the situation. Here we will use the convolution neural network to enhance the image.

Convolution Neural Network [17~19]is a kind of multilayer supervising learning neural network. Its basic structure is shown in the figure below:

![CNN Structure](Figure4.jpg)

Figure4 shows that, the low level of CNN network is formed by the convolution and maximum pool sampling layers alternately; the top level of CNN network are connected by a layer corresponds to the traditional multi-layer perceptron implied and logistic regression classifier. For the convolution layer, the operation process is as follows:

$$x'_j = f \left( \sum_{i \in M_i} x^{-1} \times k^i + b^i \right)$$  \hspace{1cm} (23)

Where $M_i$ is the set of all the input maps; $b^i$ is the offset of all the output maps.

For the sub-sampling layer, there are $N$ input ports and $N$ output ports, the calculation formula is as follow:

$$x'_j = f \left( \beta \downarrow \left( x^{-1} \right) + b^i \right)$$  \hspace{1cm} (24)
Where down is the sampling function; \( \beta \) is the multiplicative bias of each output maps; \( b \) is additive bias of each output maps. And obtain the reduced matrix through the sampling of the input matrix.

So, here we use a SAR image enhancement algorithm based on CNN.

V. SIMULATION AND ANALYSIS

A. The Resource of SAR image

For the effectiveness of the image target recognition, all the test SAR image in this paper is from Sandia National Laboratories[16], the testing SAR image is shown as bellow:

![Fig.(5): SAR Resource](image)

B. Optimization based on BSO

Here, according to the steps described above, obtain the threshold coefficient through the brainstorming optimization algorithm, the optimization process of \( K_{BSO,\text{opt}} \) is shown in figure 6.

![Fig.(6): The Optimization Process Of KBSO](image)

According to the simulation results in the figure 6, through brainstorming optimization algorithm, the corresponding threshold coefficient can be converged quickly after 10 times, And eventually converges in 0.565. Through the optimizing, the conclusion shows that when the optimization parameter is 0.565, the algorithm will obtain the best performance.

C. Performance SIMULATION

The simulation parameters in this experiment is shown in table 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>The type of tower filter</td>
<td>maxflat</td>
</tr>
<tr>
<td>The decomposition layers of tower filter</td>
<td>3</td>
</tr>
<tr>
<td>Direction filter</td>
<td>Dmaxflat7</td>
</tr>
<tr>
<td>The number of Direction filter</td>
<td>8</td>
</tr>
<tr>
<td>Kbso</td>
<td>0.565</td>
</tr>
<tr>
<td>The number of Brainstorming class</td>
<td>5</td>
</tr>
<tr>
<td>The size of Brainstorming population</td>
<td>100</td>
</tr>
</tbody>
</table>

Through the above parameters, the algorithm can obtain the following results:

![Fig.(7): SAR Image Filter](image)

Figure 7 shows that, the algorithm in this paper can obtain a better filter performance.

D. SIMULATION CONCLUSION ANALYSIS

In order to reflect the performance of the new type SAR image filter, here we use other algorithm to compare. Here we will compare with the methods of Lee filtering algorithm[17], wavelet filtering algorithm [18] and filtering algorithm based on CONTOURLET transformation[19]. The Simulation results of four filtering algorithm is shown in the figure below:

1). Algorithm in this paper whole and local image

2). Lee filter whole and local image

3). Wavelet filter whole and local image
Simulation results show that this algorithm has the best enhance the SAR image through CNN network. The optimization strategy based on the NSCT domain and following formula:

\[
\text{PSNR} = 10 \log_{10} \left( \frac{2^n - 1}{MSE} \right)
\]

where \( n \) is 8, and the MSE can be calculated by the following formula:

\[
MSE = \frac{1}{mn} \sum_{i=1}^{m} \sum_{j=1}^{n} (f(i,j) - K(i,j))^2
\]

The PSNR value are shown in table 2 below:

<table>
<thead>
<tr>
<th>Algorithms</th>
<th>PSNR</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Algorithm in this paper</td>
<td>31.22</td>
<td>385s</td>
</tr>
<tr>
<td>2. Lee filter</td>
<td>27.75</td>
<td>48s</td>
</tr>
<tr>
<td>3. Wavelet filter</td>
<td>28.45</td>
<td>140s</td>
</tr>
<tr>
<td>4. CT transformation</td>
<td>29.55</td>
<td>220s</td>
</tr>
</tbody>
</table>

According to the simulation results in the table 2, the PSNR value of filtering algorithm proposed in this paper can reach 31.22, but due to the complexity of the algorithm, its simulation time is the longest which is 385s. And Lee filter algorithm, the simulation time at least, but its worst performance the PSNR is only 27.75. To sum up, the filtering algorithm proposed in this paper, its performance is better than the filter algorithm based on CT transform, and wavelet filtering algorithm times change, Lee filter effect is the worst.

VI. Conclusions

Conflict of Interest

Acknowledgment

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