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Evaluation of Jamming Effect on SAR Based on Textural Feature

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Abstract. This paper presents a new algorithm which is based on the textural feature of Synthetic Aperture Radar (SAR) images to calculate the structural similarity in weighted wavelet domain that evaluates SAR jamming effect. Evaluation of jamming effect is useful in many visual processing systems, but challenging to perform in line with the human perception. In this paper, a method of textural feature extraction from SAR image based on Gray Level Co-occurrence Matrix (GLCM) and contrast feature is proposed. This method is mainly based on the concept of structure similarity index and its characteristic feature is consistent with perceptual property of Human Visual System (HVS). The experiment results illustrate that the contrast textural feature extracted and its evaluation index can not only calculate the disturbance between the primitive and the jammed SAR images, but also be consistent with the professional judgment of the staffs about SAR images.

Keywords: Synthetic Aperture Radar (SAR), jamming effect evaluation, contrast textural feature, structure similarity (SSIM), wavelet domain.

1. Introduction

Synthetic Aperture Radar (SAR) is a well established microwave sensing technique and using pulse compression technology and comprehensive aperture principle to obtain two-way high resolution radar image at distance and azimuth [1]. SAR enables high resolution measurements of the earth surface independent of weather conditions and sunlight illumination. In recent years, jamming technology for SAR has been greatly developed. In order to prevent enemy from gaining valuable information on SAR images, the jamming greatly damages the quality of SAR images. So it is necessary for us to find effective ways to evaluate SAR jamming effect.

In generally, the evaluation of jamming effect on SAR image is divided into subjective evaluation and objective evaluation. The subjective evaluation usually needs to find experts in this field to score the jamming image, which requires experts' knowledge, the level of understanding, as well as the perspective which needs to be sharp and accurate enough [2]. So subjective evaluation is complicated to be used in practice. The objective evaluation method gives the quantitative index or parameter which can evaluate the difference quality before and after jamming according to the mathematical model [3]. Han proposed structure similarity (SSIM) as the evaluating method [4]. These evaluation index parameters reflect the jamming effect to some extent.

However, any image is not the simple set of pixels. These traditional objective evaluations consider a single pixel or all pixels characteristics only, without considering the relationship between neighbouring pixels. So it is not fit for the perceptual property of the Human Visual System (HVS). In view of the shortcomings of traditional methods, this paper presents an algorithm to calculate the structural similarity in weighted wavelet domain using textural feature of SAR image. The structure of the paper is as follows. Section 2 introduces the textural feature of SAR image, and provides how to extract the contrast textural feature. Section 3 provides the new algorithms to evaluate SAR jamming effect. Section 4 gives the evaluate results of different jamming methods. Section 5 presents the conclusion.

2. Textural Feature

Based on the imaging characteristics of SAR image, we know that the gray value reflect the characteristics of surface features on the radar backscatter. If the different surface features have the same or similar gray value, its distribution becomes more complex. So it makes these methods ineffective based on

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gray pixel ways. In order to improve the accuracy of the evaluation, the textural feature of the SAR image is used to solve this problem. The textural feature is a visual characteristic, which reflects the image of homogenous phenomena, and it is the inherent characteristics of the object surface.

2.1. Image pre-processing

As the SAR image has speckle noise, the proper filtering algorithm is used to suppress speckle noise of image before extracting the textural features. An adaptive window and weighted coefficient of Lee filter algorithm is adopted to improve the filtering effect. Based on Lee filter [5], an adaptive method for window size and also weighted coefficient are improved in image pre-processing.

2.2. Textural feature extraction

The method extracting textural feature based on Gray Level Co-occurrence Matrix (GLCM) has a good description on the details and randomness of texture, and proves to be highly adaptable [6,7]. The GLCM is the most representative of second-order statistical method to calculate textural feature.

Suppose d is a displacement vector (dr, dc), which dr is the displacement of line direction and dc is the displacement of column direction, the GLCM C_d is defined:

$$C_d[i,j] = |\{[r,c] \mid I[r,c] = i, I[r+dr, c+dc] = j\}| \quad (1)$$

Where i and j represent the gray value of image.

Usually there is normalized GLCM:

$$N_d[i,j] = \frac{C_d[i,j]}{\sum_i \sum_j C_d[i,j]} \quad (2)$$

When value of the GLCM is normalized between 0 and 1, these values can be interpreted as probability.

Based on calculating the GLCM, various parameters can be calculated to describe the textural features. A great amount of experiments including the parameters of angle second moment, entropy, contrast and homogeneity has been taken. From them, the contrast feature is proved to be the optimal one.

The contrast textural feature description is as follows.

$$CON = \sum_i \sum_j (i-j)^2 N_d[i,j] \quad (3)$$

For coarse texture, the values of $N_d[i,j]$ are concentrated near the main diagonal. Thus, if $(i-j)$ is smaller, the contrast is also smaller. On the contrary, for the fine lines, there is a relatively large contrast.

In the paper, the window is chosen as size 4×4, compression gray level of the SAR image $L = 16$, and the displace vector $(1, 0)$.

The data of SAR image comes from Sandia lab, as shown in Figure 1, the size of the SAR image is 800×800, and its contrast textural feature is shown in Figure 2.

Fig.1: SAR image.

Fig.2: The contrast textural feature of Fig.1.

3. The New Algorithm To Evaluate SAR Jamming Effect

3.1. Contrast sensitivity function (CSF)

The most unique human visual system (HVS) model has been shown as follows:

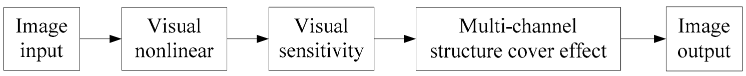


Fig.3: The most unique HVS model.

Contrast sensitivity function (CSF) represents the model of visual sensitivity band-pass characteristics. Mannos established a transfer function of approximately the form [8],

$$A(f) = 2.6 \times (0.0192 + 0.114 f)\exp[-(0.114 f)^{1.1}] \tag{4}$$

Where $f = \sqrt{f_x^2 + f_y^2}$ is spatial frequency (cycles/degree), f_x and f_y stand for horizontal direction and vertical direction spatial frequency.

A normalized CSF curve in different direction is shown in Fig.4.

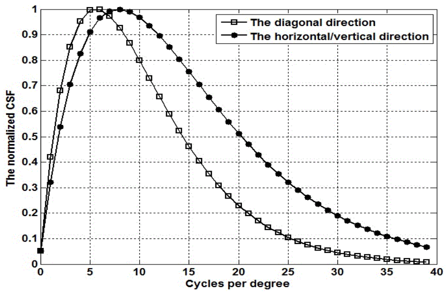


Fig.4: A normalized CSF curve in different direction.

3.2. SSIM

HAN proposed that image quality evaluation method based on SSIM [4]. Because SSIM is the similarity rather than the difference of two images needs to be compared, the quality of two images is predicted objectively. SSIM in two images is defined as those attributes representing images' structures within the scene, independent of the average luminance and contrast. Similarity measurement has three independent components: luminance, contrast, structure, that combined to yield an overall similarity measurement:

$$SSIM(x, y) = [l(x, y)]^{\alpha}[c(x, y)]^{\beta}[s(x, y)]^{\gamma} \tag{5}$$

Where x represents the primitive image and y represents the jammed image, $l(x, y)$ is the luminance, $c(x, y)$ denotes contrast, $s(x, y)$ represents structure, α, β, γ are weighted index, and $\alpha > 0,\ \beta > 0,\ \gamma > 0$.

Through simplified the formula (5), ordered $\alpha = \beta = \gamma = 1$, SSIM is shown as follows.

$$SSIM(x, y) = \frac{(2\mu_x\mu_y + C_1)(2\sigma_{x,y} + C_2)}{(\mu_x^2 + \mu_y^2 + C_1)(\sigma_x^2 + \sigma_y^2 + C_2)} \tag{6}$$

Where μ_x and μ_y are the means of the primitive image, σ_x^2 and σ_y^2 are the variances of the primitive image and the jammed image, $\sigma_{x,y}$ is the covariance of the two images. C_1, C_2 are constant to avoid instability when denominator is very close to zero. C_1 expressed as $C_1 = (K_1L)^2$, $K_1 = 0.01$, C_2 expressed as $C_2 = (K_2L)^2$, $K_2 = 0.03$, L is the dynamic range of the pixel values(the biggest quantitative gray scale), $L = 255$.

The range of values for SSIM lies between $+1$ to -1. The best value corresponds to $+1$, the worst is -1. The value -1 represents that the jammed image is opposite to primitive image. So $s(x, y)$ is adjusted as follows:

$$\hat{s}(x, y) = \frac{|\sigma_{x,y}| + C_3}{\sigma_x\sigma_y + C_3} \tag{7}$$

And the SSIM can be expressed as

$$SSIM^{'}(x, y) = \frac{(2\mu_x\mu_y + C_1)(2|\sigma_{x,y}| + C_2)}{(\mu_x^2 + \mu_y^2 + C_1)(\sigma_x^2 + \sigma_y^2 + C_2)} \tag{8}$$

When the images' quality is evaluated, the image is divided into M blocks according to experience, calculated each block of SSIM, and averaged these values of SSIM. So Mean-SSIM ($MSSIM$) can be expressed as follows:

$$MSSIM = \frac{1}{M}\sum_{j=1}^{M} SSIM^{'}(x_j, y_j) \tag{9}$$

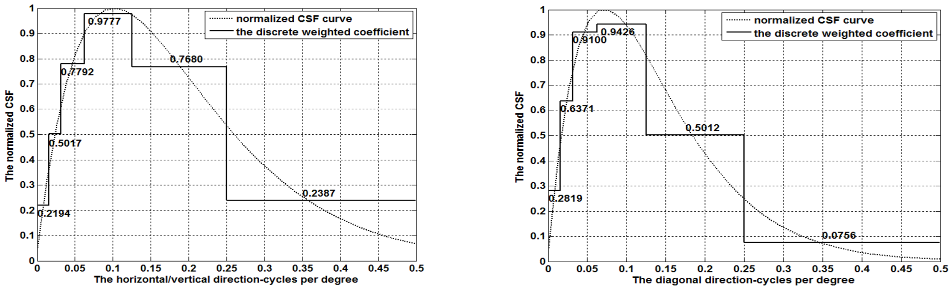
From formula (9), it shows that the higher the value of $MSSIM$, the smaller the loss of image quality.

3.3. Textural feature's SSIM and weighted CSF in wavelet domain (WWCTS)

Let it borrow from the MSSIM of contrast feature has high correlation between the CSF, and take use of one of the biggest features of the wavelet decomposition, which is only decomposes low frequency space in high and low. Each band is the original image in different resolution subplot, which maintains the basic outline of the original image. Meanwhile, outline is the most important structural information. Wavelet transform can't loss image structure information, and it is just a different form of structural information. So, the method textural feature's SSIM and weighted CSF in wavelet domain (WWCTS) are proposed.

According to the CSF's theory, N series of decomposition, and the average value as discrete frequency of weighted value in absolute process for each frequency in the CSF curve are calculated.

After the above preliminary treatment, the discrete and normalized CSF curves are shown in Fig.5.



(a) The horizontal/vertical direction. (b) The diagonal direction.

Fig.5: The discrete and normalized CSF curves.

WWCTS is got by transforming SSIM in gray images into textural feature. The basic calculation steps of evaluation index are as follows:

(1) Image pre-processing by using modified Lee filter.

(2) Calculate the GLCM of the primitive SAR image and the jammed SAR image, GLCM1 and GLCM2.

(3) Calculate contrast textural feature, CT1 and CT2.

(4) Decompose CT1 and CT2 into N series of wavelet decomposition. From the experiments, $N=5$ is the best series.

(5) Let the weighted of the lowest frequency components (LF5) equal 1. Other coefficients, according to their proportion of LF5, calculate each weighted coefficient $w_{i,j}$ in different direction.

(6) Calculate similarity $tssim_{i,j}$ in each band using formula (9).

(7) Calculate the evaluation index of the jammed effect WWCTS using formula (10).

$$\mathrm{WWCTS}(X,Y)=\left(tssim_{LL5}+\sum_{i=1}^{3}\sum_{j=1}^{5}w_{i,j}\cdot tssim_{i,j}(x_{i,j},y_{i,j})\right)\Bigg/\left(1+\sum_{i=1}^{3}\sum_{j=1}^{5}w_{i,j}\right) \quad (10)$$

Where $i=1$ stands for horizontal direction, $i=2$ stands for vertical direction and $i=3$ stands for diagonal direction, j stands for wavelet series, $0\le \mathrm{WWCTS}\le 1$. If WWCTS is relatively larger, it means that jamming effect is less effective; on the contrary, the jamming effect is much better.

The values of $w_{i,j}$ are shown in Table 1.

Table 1: The value of the weighted coefficient $w_{i,j}$

$w_{i,j}$	*j=1*	*j=2*	*j=3*	*j=4*	*j=5*
Horizontal (*i=1*)	0.85	2.72	3.47	2.76	1.82
Vertical (*i=2*)	0.85	2.72	3.47	2.76	1.82
Diagonal (*i=3*)	0.27	1.78	3.34	3.23	2.26

4. Experiment Results

In order to verify the availability and accuracy of WWCTS, several different jamming styles such as Radio Frequency (RF) noise, multiplicative noise, and jamming working on different directions are used in the SAR image.

(1) Image jammed by different RF noise.

Three jammed images are given by RF noise [9] in different Jam Signal Ratio (JSR). The jammed images are shown in Fig.6.

(a) JSR=36 dB (b) JSR=24 dB (c) JSR=14 dB

Fig.6: The jammed SAR images by different RF noise.

(2) Image jammed by different multiplicative noise.

Three jammed images are given by multiplicative noise in different JSR. The jammed images are shown in Fig.7.

(a) JSR=36 dB (b) JSR=24 dB (c) JSR=14 dB

Fig.7: The jammed SAR images by different multiplicative noise.

(3) Jamming acts on different directions.

The jammed images are shown in Fig.8.

(a) Horizontal/Vertical. (b) Diagonal.

Fig.8: The jammed SAR images by jamming acts on different directions.

Viewing these jammed images, the jamming effect by RF noise is much more effective than multiplicative noise's in the same JSR. Jamming working on horizontal/vertical direction is much more efficient than diagonal direction, because human eyes are much sensitive to horizontal/vertical direction.

According to the WWCTS, the jamming effect is calculated. The results are shown in Table 2. In order to verify the WWCTS is availability, MSSIM for comparison is chosen.

Table 2: The results of jamming effect

Images	JSR=36dB	JSR=24dB	JSR=14dB	JSR=36dB	JSR=24dB	JSR=14dB	Horizontal /vertical	diagonal
WWCTS	0.26	0.66	0.87	0.33	0.54	0.69	0.66	0.75
MSSIM	0.94	0.46	0.61	0.57	0.77	0.82	0.88	0.90

From the Table 2, we see clearly that, the evaluation index of the traditional pixel-based statistical characteristics-MSSIM is not accurate, especially when the jamming is much strong. By subjective judgement, Fig.6 (a) is much worse than Fig.6 (b), Fig.7 (b) is worse than Fig.6 (b), but MSSIM doesn't give the correct evaluation. But WWCTS is a better evaluation way, it can reflect subjective feelings of human eyes observation than traditional methods. The value of WWCTS becomes smaller with jamming becoming stronger, and it is not affected by different jamming styles. In the same JSR, different jamming style has different jamming effect and different damage effect to image information. The result is consistent with the professional judgment of the staffs about SAR images.

5. Conclusions

A new algorithm based on WWCTS to evaluate SAR jamming effect has been presented in the paper. The results show that the contrast textural feature extracted and its evaluation index can not only calculate the disturbance between the primitive and the jammed SAR images, but also be consistent with the professional judgment of the staffs about SAR images. Meanwhile, this paper has also shown that in the same JSR, different jamming style has different jamming effect and different damage effect to image information. The WWCTS is much better than traditional methods, and the complexity of the algorithm is lower, also it is conducive to engineering practices.

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