A Promotion SAR Raw Data Compressing Algorithm Based on BAQ

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Abstract—**BAQ algorithm is widely used in SAR raw data compressing, but SAR raw data does not perfectly submit to normal distribution in some cases. One of situation is fractional saturation of raw data. This paper proposes a promoted BAQ algorithm to compress SAR raw data by changing the quantization algorithm. The promoted algorithm increase the SNR of rebuild data with little bandwidth burden.**

Keywords-SAR;BAQ;raw data

I. INTRODUCTION

Synthetic Aperture Radar (SAR) is an imaging radar which can work in any weather and any time. Now SAR is widely used in military surveillance, geoscience and remote sensing. SAR could get high-resolution image, but SAR raw data is too large and difficult to be transmitted. Compressing of SAR raw data is a meaningful way to enhance image quality and to save bandwidth of downlink. Block adaptive quantization (BAQ) algorithm is simple and effective, and was firstly used in Magellan mission then widely accepted by many SAR systems. A lot of new algorithms presented these years are based on it. But for city and coast area, SAR raw data contain too much signal of saturation. Navneet Agrawal and K. Venugopalan [1] presented to compensate power loss. Zhao [2] presented fractional saturation block adaptive quantization (FSBAQ) based on BAQ algorithm. Qi [3] improve LIoyd-max quantizer by add a correction term. Masanobu Shimada [4] also take about this question by radiometric correction. In order to deal with fractional saturation signal, this paper presents a new algorithm to promote BAQ algorithm. The promotion of algorithm use an equal and adaptive quantization level which is determined by the max data in each blocks, and transmit the quantization level and the code to ground segment. This algorithm could hold high SNR both for fractional saturation signal and normal signal with low hardware burden.

Section Ⅱ is an overview of BAQ algorithm and cause fractional saturated data. Our promotion algorithm is presented in section Ⅲ. Section Ⅳ shows the simulation result of the promotion algorithm. Finally, a summary is provided in section Ⅴ.

II. BAQ ALGORITHM AND SIGNAL ANALYSIS

SAR emission chirp and receive the addition echo of many scatters. Radar echo is downconverted to baseband and divided into I and Q channel. I and Q signals separately digitized by A/D converters. Then signals are computed and encoded to 2 or more bits. The statistic are assumed to be Gaussian distribution, zero means, identical variances and unknown average power. A brief introduction is given here.

Echo in observation point can be written as:

$$A(x, y, z) = \sum_{i=1}^{k} A_k e^{j\psi k} \qquad (1)$$

There $A(x, y, z)$ is represented the sum echo of scatters, A_k is the amplitude of echo, ψ_k is the phase delay due to the different paths and radar wavelength and is independent of A_k. Thus echo can be assumed to have such property: A_k and ψ_k are independent of each other, so does different echo. ψ_k are uniformly distributed on the interval $[-\pi, +\pi]$.

It shows that the real and imaginary parts of the signal have zero means, identical variances, and are uncorrelated. There is a large number of scatters because of the large illumination area by SAR. I and Q signal are the addition of a large number of independent random variables. According to the central limit theorem that $N_s \rightarrow \infty$, I and Q signal are submit to Gaussian distribution with unknown variances.

According to the property, the real and the imaginary part of the signal are statistically independent. Also, the signal submit to Gaussian distribution, zero means, identical variances and unknown average power.

Above all, the BAQ algorithm compress SAR raw data by dividing data into small blocks in range and azimuth. The size of each blocks often decide by user, but the block neither can be too tiny nor too large. Too tiny block may not be assumed to be Gaussian distribution for each block, too large block would loss the changes of range and azimuth data. Then, encode the data by variance of the block. The core of BAQ algorithm is LIoyd-max quantizer [5], it

designs by the principle of minimum mean squared error. Average possibility of two rebuild values treat as quantization value, Average value of two quantization values treat as rebuild value, quantization value and rebuild value are repeated substitution in this algorithm. In practical application, the thresholds of the quantizer are calculated in advance and bring it in a table. The outputs of BAQ algorithm relies on the table.

BAQ algorithm working in the following order (example for 2 bits quantization):

(1). Divide data into blocks in range and azimuth, that means, divide the data matrix to many small blocks in same scale. Then, calculate the variance of each blocks.

(2). For data of each blocks, encode the data by comparing with the output table of LIoyd-max quantizer. Code is depended on the different areas data is in.

(3). Transmit code and variance information to ground segment and then rebuild the original data matrix by look up the decode table.

The encode and decode table is given here. (σ represent the variance of the data block)

Table 1 encode and decode table

Compare standard	encode output	Decode output
$x \in (0.9816\sigma, \infty)$	01	1.5101σ
$x \in (0, 0.9816\sigma)$	00	0.4528σ
$x \in (-0.9816\sigma, 0)$	10	-0.4528σ
$x \in (-\infty, -0.9816\sigma)$	11	-1.5101σ

For the encode segment (space segment), the first code is 1 if the data is negative, the first code of positive data is 0. The absolute value of data between 0 and 0.9816σ are encode to 0, while 1 which is between 0.9816σ and ∞. For decode segment, the code 01 are decoded to 1.1501σ, the code 00 are decoded to 0.4528σ and so on.

BAQ algorithm processes SAR raw data based on the properties of Gaussian distribution and zero means. For city and coast area, many signals would be saturation, then SAR raw data is no longer submit to normal distribution. For original BAQ algorithm, this kind of signal distribution would decline the SNR. So a lot of promotion algorithms were presented to overcome the barrier.

Now many SAR systems are using 8-bit A/D converter. In some case, the data would be saturation because of a large dynamic range or an unsuitable receiver setting. The signal beyond the dynamic of A/D converter will reach the clipping point of A/D converter, it lead to an unknown SNR degradation. Apparently, this situation fit not the condition of optimization quantization.
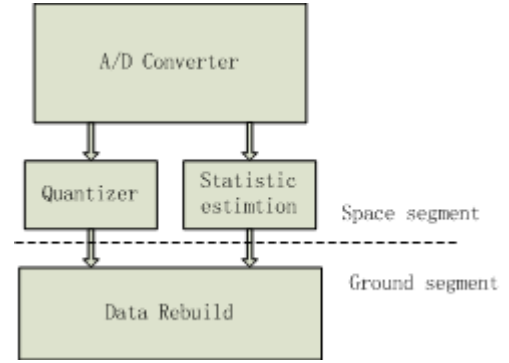

Figure 1   signal processing

The average power of signal are can be written as:

$$|\bar{I}| = |\bar{Q}| = 2\sum_{n=0}^{N-1}(x_n + 0.5)\int_{x_n}^{x_n+1} p(x)dx \qquad (2)$$

And

$$p(x) = \frac{1}{\sqrt{2\pi}\sigma}e^{-x^2/2\sigma^2} \qquad (3)$$

so the relationship of average power and variance is:

$$|\bar{I}| = |\bar{Q}| = 127.5 - \sum_{n=0}^{127}erf(\frac{n+1}{\sqrt{2}\sigma}) \qquad (4)$$

The large area target which is distributed separately often lead to signal saturation because of the high echo power. Thus saturation raw data no longer submit to Gaussian distribution.
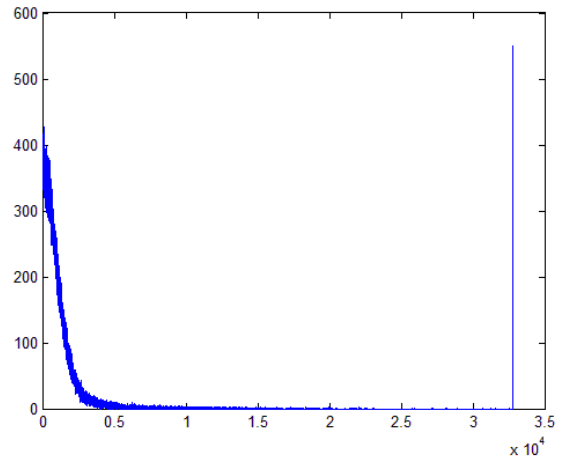

Figure 2   Saturation SAR raw data

According to the properties of statistic, original BAQ algorithm is based on Gaussian distribution, zero means, identical variances and unknown average power. But fractional saturation signal contain a lot of saturation data, which lead to a breakage to the Gaussian distribution. We can see from the table that the middle area of statistic submit to the Gaussian distribution. The maximum and minimum area are contain more data than normal statistic.

III. A PROMOTION OF BAQ ALGORITHM

In the practical star-borne SAR, data is compressed to 2 bits code. The first bit is sign bit, so we just use 1 bit to express the magnitude of data. In this way, the minimum and the maximum data would not influence the rebuild result. For 3 or 4 bits quantization, this kind of data severely decrease the SNR of rebuilding statistic. Zhao presented fractional saturation block adaptive quantization (FSBAQ) based on BAQ algorithm. The core of the algorithm is to change the code length. When signal saturation is not heavy, original BAQ is used. When signal saturation become serious, FSBAQ will be used. And FSBAQ use 1 more bit to encode the maximum and minimum data. This method increases the Signal to Noise Ratio (SNR). But the bit rate of FSBAQ is instable, which lead to a more complex hardware, a unstable downlink bandwidth and lower speed.

For this problem, Qi improve LIoyd-max quantizer by add a correction term, and compensate the extra power in the decoder. The practical realization of this promotion change the lookup table in the RAM instead of FPGA and VHDL. Like FSBAQ, this method spend a lot to apply different compressing strategy.

Base on this, we bend to promote a new algorithm to compress both normal and saturation statistic. Which means to increase the SNR for saturation data and decrease the SNR loss for normal data. The new algorithm as follow:

Like the original BAQ algorithm, the new algorithm firstly divide raw data into suitable blocks, which could both keep similar-Gaussian distribution and slow-change variance. Then make each blocks Gaussian standardization by variance and average power. For the quantization segment, the first encode bit 0 represent positive value, 1 represent negative value. Finding the biggist data as max rebuild value in each blocks, and divide this value into equal rebuild level.

The average between two rebuild values is a quantization level, all signals fall into two quantization level are quantized to a same quantization code. In this way, the quantization strategy could see like this.
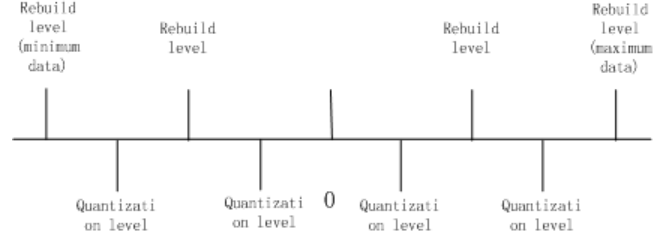

Figure 3   quantization level choosing

According to the quantization areas and rebuild values, this algorithm compress and rebuild SAR raw data in the following order:

(1). Divide data into blocks by range and azimuth, divide the data matrix to many small blocks in same scale. Calculate the average and variance of each block. Convert the raw data into strict Gaussian distribution using the block average and variance.

(2). If the data is negative, the first code is 1, the first code of positive data is 0. Then find the max absolute value in the strict Gaussian distribution matrix, divide this max value equally into quantization level. Encode the rest of quantization bits by the absolute value of the data.

(3). Transmit code, quantization level, average and variance information to ground segment. Rebuild the strict Gaussian distribution by multiply the quantization level and code, and rebuild the data.

The distance between quantization levels and that between decode levels is equal. At the same time, this algorithm keep the biggest data in each blocks, decoded data could keep the original signal distribution, especially in the quantization bit higher than 3 bit. This method work well for fractional saturation data, enhance the SNR and improved image quality. For normal signal, this algorithm would not make image quality too bad. This algorithm would cost a bit more data, thus cost more downlink bandwidth. This algorithm has better adaptive quality than other promotion algorithm, notably increase the SNR for fractional saturation data.

The promotion algorithm could get higher SNR than original algorithm, and would not lose the original SNR for small data.

IV. SIMULATION RESULT

In order to compare the compressing quality. We use Mean Squared Error and PSNR to compare the image.

$$MSE = \frac{1}{P \times Q} \sum_{p=0}^{P-1} \sum_{q=0}^{Q-1} [\sigma(p,q) - \hat{\sigma}(p,q)]^2 \qquad (5)$$

And

$$PSNR = -10 \lg[\frac{255^2}{MSE}] \qquad (6)$$

In normal, The image would be better with lower MSE and higher PSNR.

Table 2   simulation result

Data	PSNR	MSE
Raw data	28.9321dB	3.5165e+008
Original BAQ	28.8733dB	3.5376e+008
Promotion algorithm	28.8963dB	3.4876e+008

We can see from the table, the promotion algorithm has a higher PSNR and lower MSE than original BAQ algorithm. Thus, this algorithm would get better result for saturation raw data.
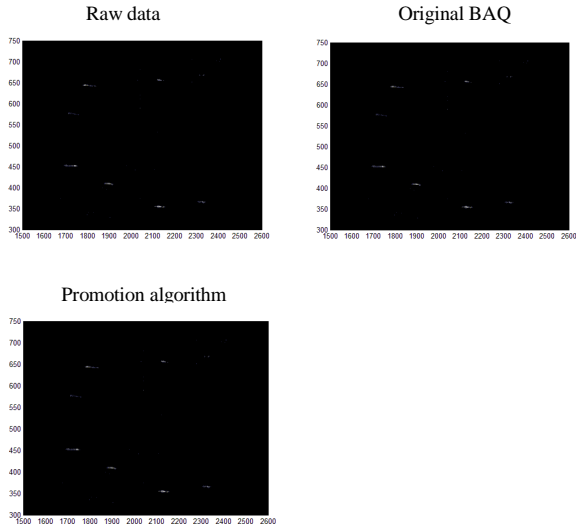

Figure 4   image quality compare

The quality of image using promotion algorithm is better than which using the original BAQ. And the image quality increase more for higher degree of raw data.

According to simulation result and image compare, we can see the promotion algorithm has better effect for Saturation raw data processing

V.   SUMMARY

Simulation result indicate that the promotion algorithm suitable for fractional saturation data, notably improve image quality for city and coast area. Furthermore, the image quality falls little for other observation object.

But this algorithm is complex, comparing with the original one. Also the algorithm need to be improve the capability to deal with normal data.

ACKNOWLEDGMENT

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