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SAR SIGNAL PROCESSING ALGORITHMS

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ABSTRACT

In space borne SAR systems some form of data compression is required to reduce the bandwidth of the downlink channel. In the present paper we have represented the complex SAR raw data with magnitude-phase (MP) and then applied the devised algorithm. It is observed that the phase information of the compressed data is preserved to the great extent. The quality of the reconstructed data is compared in terms of the important performance evaluation parameters like signal to noise ratio (SNR), standard deviation of the phase (PSD), mean phase error (MPE) and the compression ratio (CR). The magnitude-phase algorithm (BMPQ) is compared with that of Block Adaptive Quantization (BAQ) algorithm. The evaluation procedure is carried out in two domains, raw data domain and image domain. Numerical experiments were carried out using ERS-2 satellite data supplied by European Space Agency (ESA) showing that magnitude-phase algorithm provides us with more Compression Ratio (CR) choices than BAQ and for certain CR, MP algorithm provides at least one choice whose performance is better than or equal to that of BAQ. These two algorithms neither affect spatial resolution nor generate geometric distortion. Both of them have only a little effect on radiometric resolution.

Keywords: data compression, synthetic aperture radar, block adaptive quantizer, block magnitude phase quantizer.

1. INTRODUCTION

The quantity of space borne SAR raw data is large, but the capability of on board data storage and down link bandwidth is limited. Therefore raw data must be compressed before downlink. These techniques are usually referred to as raw data compression, which are classified into three different categories according to the methods of quantization viz scalar, vector, and transform domain of compression. BAQ has been used in Magellan [2] and SIR-C [3], respectively for on-board data compression due to its simplicity for coding and decoding. Owing to the high entropy of SAR raw data, data compression always causes a loss of information, i.e. compression is associated with image quality degradation. Moreover, data compression algorithms must provide satisfactory phase accuracy in order to meet the needs of polarmetric and interferometric applications. Since current SAR system usually has various applications, compression algorithms should have different choices of data rate adaptively [4]. Yao [1] proposed a new algorithm for SAR raw data compression, i.e., compressing the amplitude and phase of SAR raw data respectively, however, the performance of it has not been analyzed yet. This paper mainly evaluates the performance of amplitude-phase algorithm via comparing with BAQ based on ERS-2 data.

2. BASIC MODEL OF SAR RAW DATA

Synthetic Aperture Radar data are random in nature and the samples are having very poor entropy in the individual samples but according to central limit theorem when we deal with a group of sample data and try to get the statistics then it is found that they exhibit certain useful characteristics. When we plot the graph it is found that I (In-phase) and Q (Quadrature-phase) channels of SAR data are Gaussian distribution with zero mean [9]. In order to maintain these characteristics, proper selection of the block of data is to be ensured. The data block selection is made in such a way that the distribution of the complete block is Gaussian and the power from sample to sample through out the block almost remains constant apart from the overall mean near to zero. In our experimental analysis we have found that representation of SAR raw data in polar format instead of Cartesian coordinates changes the shape of the curves completely and the magnitude part of the echo has Rayleigh distribution while the phase is uniformly distributed on the interval [-π, π]. The magnitude and the phase are statistically independent of each other. Shape of the curve decides the type of quantization technique to be adopted for the encoding and decoding of the SAR image or raw data. We have shown histograms of I and Q channels of ERS-2 raw data and their magnitude and phase parts in Figure-1.

3. BASIC PRINCIPLE OF BAQ

BAQ algorithm is based on the fact that the dynamic range of the signal power within a chosen data block (0 to 255 or -128 to + 127) is much less than that of the whole data set [2, 4]. Basic block arrangement for data compression using BAQ is shown in Figure-2. The first step is to divide the raw data into blocks of small size with respect to the whole data set.

The minimum block size is selected in such a way as to ensure Gaussian statistic distribution within a block and the maximum block size is limited by signal power, which should remain constant through out the block [3]. The standard deviation of each block is estimated by the following formula.

$$\sigma = \sqrt{\frac{1}{MN}\sum_{i=0}^{M-1}\sum_{j=0}^{N-1} x_{ij}^2} \quad \text{....(1)}$$

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Where M, N are the sample numbers of the row and the column of the block, respectively. For the optimal operating point [8], the threshold values (delta) are proportional to the standard deviation of each data block. This is shown in Figure-3.

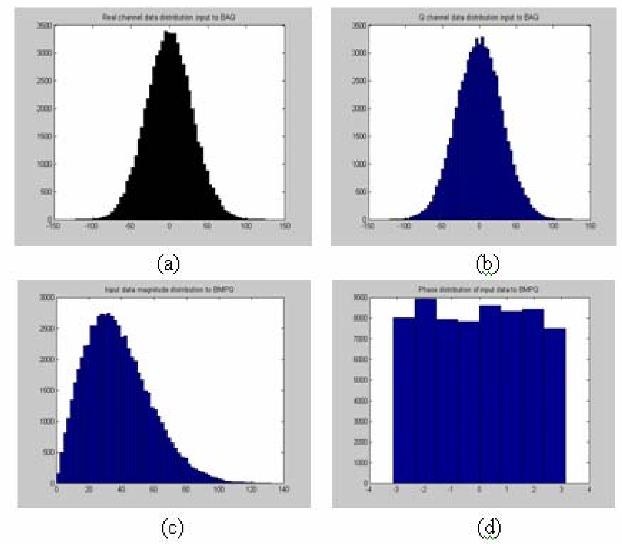

Figure-1. (a) Histogram of I channel; (b) histogram of Q channel; (c) Histogram of the amplitude of raw data; (d) Histogram of the phase of raw data.

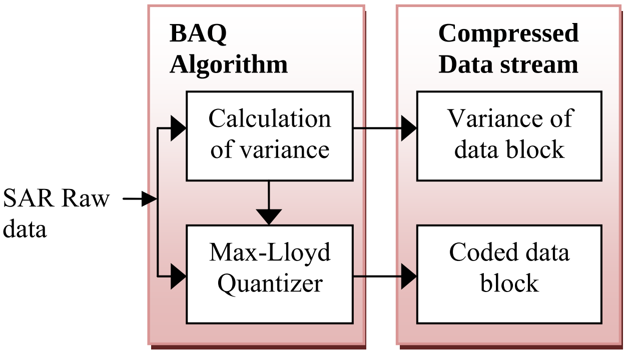

Figure-2. Block diagram of standard BAQ algorithm.

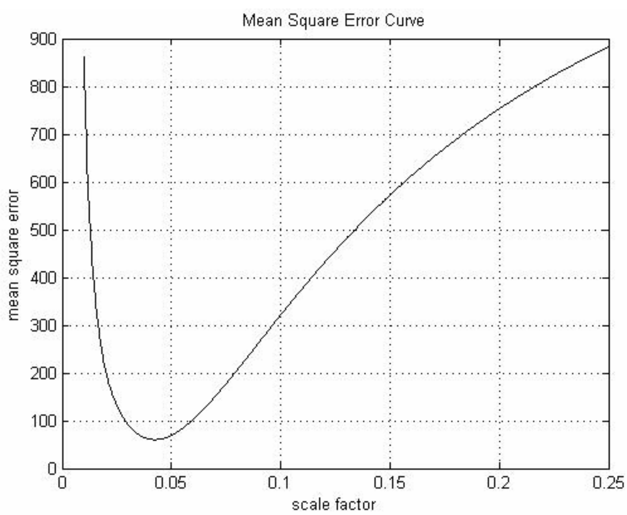

Figure-3. Curve showing optimum threshold level.

The transition levels for quantization with fewer bits can be obtained in literature [5]. The standard deviation of each data block is transmitted and used for the decompression of the data (Figure-2). For each data block, the output levels of a non-uniform quantizer are multiplied by the standard deviation.

4. BASIC PRINCIPLE OF MAGNITUDE-PHASE (MP) ALGORITHM

A block diagram of the proposed system for SAR data compression and decompression is shown in Figure-4 in the form of magnitude phase algorithm.

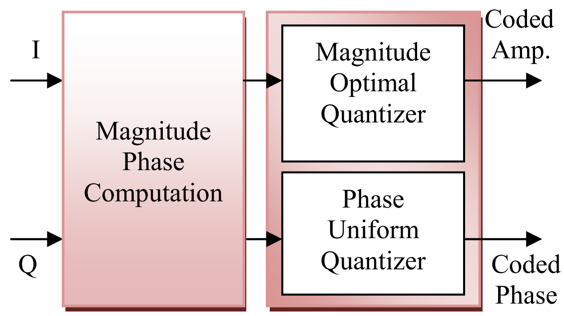

Figure-4. Amplitude phase algorithm set up.

In put to the system serve the demodulated complex SAR raw data denoted by I and Q for the In – phase and Quadrature phase components .In SAR data the magnitude and the phase are independent of each other, so we can quantize them separately. Literature [6] provides us with the optimum non uniform quantization for a Rayleigh input. At the same time, the phase is uniformly distributed on the interval [-π, π], so we quantize it uniformly.

The amplitude of the raw data can be calculated as

$$A_{ij} = \sqrt{I_{ij}^{\ 2} + Q_{ij}^{\ 2}} \qquad \text{...(2)}$$

Where i = 0, 1, 2 ….M j = 0, 1, 2 …N

Where I and Q represent I channel and Q channel raw data respectively. The phase of the raw data can be calculated as

$$\theta_{ij} = atan \frac{Q_{ij}}{I_{ij}} \qquad \text{...(3)}$$

Where i = 0, 1, 2 ….M j = 0, 1, 2 …N

In order to decrease the dynamic range of the signal, MP algorithm also needs dividing the raw data into blocks of small size [4]. We can simply refer to BAQ algorithm to divide the raw data into small blocks based on the fact that, if raw data of I and Q channel are Gaussian distributed then the magnitude is Rayleigh distributed and the phase is uniformly distributed in the [-π , π] interval. So we can easily calculate the amplitude and the phase as per equations 2 and 3. Rayleigh distribution is characterized by its distribution coefficient μ, comparing with BAQ, amplitude-phase algorithm needs normalizing the raw data by μ, and transmitting it for decompressing the coded data too.

5. ALGORITHM QUALITY PARAMETERS

In order to evaluate any compression algorithm, there are certain quality parameters which guide us choosing suitable compression algorithms according to specific applications. Usually we can evaluate a compression algorithm based in raw data domain, image domain and certain application domain. The forenamed two evaluation domains are universal methods to evaluate all the algorithms for SAR raw data compression. At the same time, evaluation based on certain application domain can guarantee the compression algorithm and Compression Ratio (CR) reaching the best choice for specifically application, like interferometric SAR needs maintaining accurate phase information [7]. In this paper we fix attention on raw data domain and image domain along with compression ratio in order to provide a universal approach to evaluate compression algorithms. Figure-5 shows the block diagram of evaluation flow based on this method.

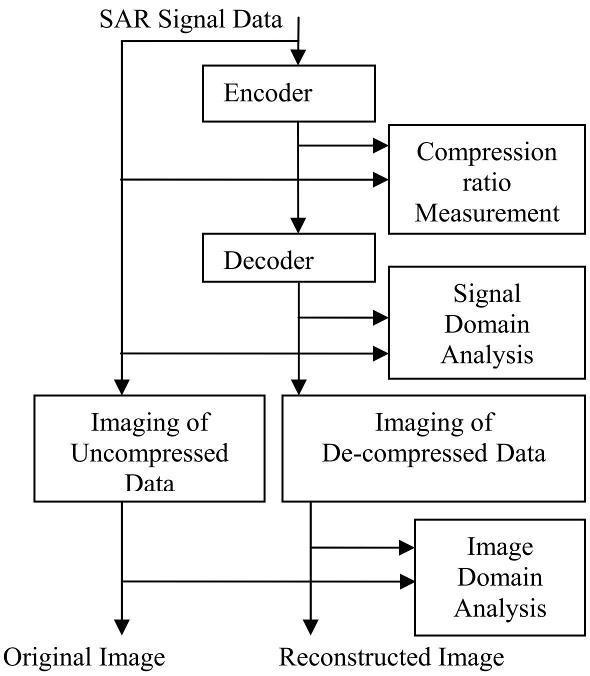

Figure-5. Block diagram of evaluation flow.

5.1. Raw data domain basis quality parameters

SNR is a global parameter that allows comparison of different compression algorithms. It is defined by

$$SNR = 10log\left[\frac{\frac{1}{K_aK_r}\sum_{i=1}^{Ka}\sum_{j=1}^{Kr}Xij^2}{\frac{1}{K_aK_r}\sum_{i=1}^{K_a}\sum_{j=1}^{K_r}(X_{ij}-\overline{X_{ij}})2}\right] \quad ...(4)$$

Where x_{ij} and xij bar are the input sampled data and decoded data respectively. *Ka* and *Kr* are the azimuth number and the range number of the whole data set. As for interferometric applications, accurate phase is indispensable, this paper used Phase Standard Deviation (PSD) and Mean Phase Error (MPE) to evaluate Polar algorithm (BMPQ) and BAQ. They are defined as

$$MPE = \frac{1}{K_aK_r}\sum_{i=1}^{K_a}\sum_{j=1}^{K_r}|\emptyset_{ij} - \varphi_{ij}| \quad ....(5)$$

and

$$PSD = \sqrt{\frac{1}{K_aK_r}\sum_{i=1}^{K_a}\sum_{j=1}^{K_r}|\emptyset_{ij} - \varphi_{ij}|^2} \quad ...(6)$$

5.2 Image domain basis quality parameters

Image quality gets affected due to application of compression algorithm [8]. We define some important parameters to evaluate BMPQ algorithm and BAQ in this section. Spatial Resolution Loss (SRL) is used to evaluate the effects on spatial resolution of image including azimuth resolution loss and range resolution loss.

$$SRL = \frac{\rho_0 - \rho_c}{\rho_0} \quad ...(7)$$

Where ρ_O and ρ_C are spatial resolution of image with and without raw data compression respectively. For the point targets Peak to Side-Lobe Ratio (PSLR) and Integrated Side-Lobe Ratio (ISLR) are two useful parameters. For homogeneous targets evaluation, Radiometric Resolution (RR), is an important and indispensable one, as for single look image and is given by

$$\Gamma = 10\log\left[1+\frac{\sigma}{\mu}\right] \quad ...(8)$$

Where μ and σ are the mean and standard deviations of the power of homogenous areas. Compression ratio (CR) is another parameter which reflects the achieved compression after coding the image. This parameter is defined as the ratio of number of bits used to compress the image and the number of bits the original uncompressed input image is represented.

6. NUMERICAL EXPERIMENTS BASED ON ERS-2 DATA

Numerical experiments are carried out based on ERS-2 data (a patch of ERS-2 data for an area of Pinyon Flat, California).Some useful and important results are presented in this section followed by theoretical analysis.

6.1. Numerical results based on raw data domain

Table-1 shows evaluation results of amplitude-phase algorithm. We can draw some useful conclusions from table as follows:

Table -1: Amplitude-Phase (BAPQ) Algorithm Evaluation (256 x 256 block size).

M (b/s)	**P** (b/s)	**CR**	**SNR** (dB)	**PSD** (degree)	**MPE** (degree)
2	2	4.00	6.97	24.56	21.08
	3	3.20	11.22	13.23	11.43
	4	2.67	14.45	6.56	5.11
3	2	3.20	7.03	24.56	21.08
	3	2.67	12.44	13.23	11.43
	4	2.29	17.23	6.56	5.11
4	2	2.67	7.12	24.56	21.08
	3	2.29	12.88	13.23	11.43
	4	2.00	20.78	6.56	5.11

- The phase (P) accuracy is only determined by bits/sample used to quantize it uniformly, it has nothing to do with the magnitude(M); and
- With bits/sample of phase and/or magnitude increasing, the performance of compression is improved; however, the former is more obvious than the later.

Some important conclusions of BAQ evaluation on 256 x 256 image can be obtained from Table-2 are as follows:

Table-2. BAQ evaluation parameters (256 x 256 block size).

Channel	**CR**	**SNR** (dB)	**PSD** (degree)	**MPE** (degree)
I Channel	4.00	9.228	17.98	12.92
	2.67	13.99	11.56	9.97
	2.00	20.34	8.23	6.00
Q Channel	4.00	9.213	18.04	13.01
	2.67	13.97	11.34	10.11
	2.00	20.87	8.43	5.99

- The performance of I and Q channel are similar.
- With compression ratio reducing, the performance of I and Q channel are both improved

Comparing Table-1 with Table-2, we can summarize some conclusions as follows:

- Magnitude Phase algorithm provides us with more choices of CR, so we can choose proper one in order to obtain optimum performance according to different applications.
- In certain CR, Magnitude Phase algorithm can provide at least one choice which performance is better than or equal to BAQ algorithm.
- At the same time, the performance of Magnitude Phase (Magnitude 2b/s and Phase 4b/s) is better than the same CR choice of BAQ.

6.2. Numerical results based on image domain

Images with and without raw data compression is shown in Figure-6.

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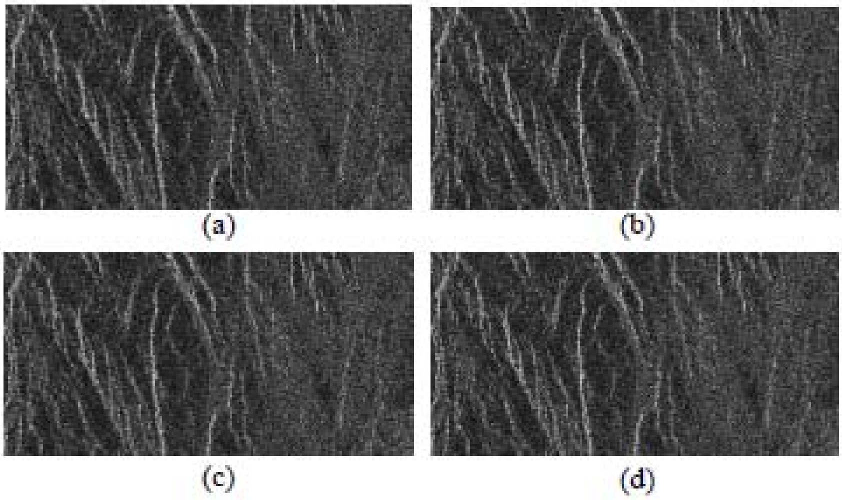

Figure-6. (a) Image without raw data compression; (b) image after BAQ using (3 + 3); (c) image after polar compression using (2 + 4); (d) image after polar compression using (3 + 3).

For BAQ, (3 + 3) means using 3 bits/sample for I and Q channel compression, respectively. For Magnitude - Phase algorithm, (2 + 4) means using 2 bits/sample for magnitude compression and 4 bits/sample for phase compression. For BAQ we have tabulated (Table-3) for 2, 3 and 4 bits / sample.

Table-3. Magnitude phase algorithm results (256 x 256 image).

Parameters	Phase			Without compression
	2 b/s	3 b/s	4 b/s	
CR	4.00	3.20	2.67	1.00
ISLR (dB)	-14.25	-13.93	-14.25	-15.02
PSLR (dB)	-20.83	-21.00	-21.15	-20.82
RR (dB)	2.141	2.199	2.216	2.23
GD	none	none	none	none

For AP algorithm we tabulate 2 bits/ sample for magnitude and 2, 3 and 4 bits /sample for phase as tabulated in Table-4.

Table-4. BAQ algorithm results (256 x 256 image).

Parameters	2 b/s	3 b/s	4 b/s	Without compression
CR	4.00	2.67	2.00	1.00
ISLR(dB)	-14.19	-14.19	-14.19	-14.20
PSLR(dB)	-21.25	-21.27	-21.28	-21.32
RR(dB)	2.211	2.239	2.236	2.23
GD	none	none	none	none

7. RESULTS, DISCUSSIONS AND CONCLUSIONS

A new coding method for SAR data processing has been discussed in this paper. The result is obtained by quantizing the magnitude and phase with different coding rates. It is possible to use magnitude-phase algorithm for complex data compression using BAQ method. For problems requiring better knowledge of phase more bits are selected for phase coding. We summarize the main conclusions of this paper here.

a) Magnitude-Phase algorithm provides us with more choices of CR, so we can choose proper one in order to obtain optimum performance according to different applications.

b) In certain CR, Magnitude-Phase algorithm can provide at least one choice, whose performance is better than or equal to BAQ algorithm.
c) The phase accuracy is only determined by the bits/sample used to quantize it uniformly, and it has nothing to do with the magnitude.
d) With CR of both phase and magnitude reducing, the performance of compression is improved; however, the former is more obvious than the latter.
e) These two algorithms neither affect spatial resolution nor generate geometric distortion. Both of them have only a little effect on radiometric resolution.

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